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STARTERS AND CONTROLLERS FOR U. S. NAVY ALTERNATING CURRENT AUXILIARY MOTORS.

By C. HUEY, Member.*

Previously, in the November, 1925, issue of the JOURNAL, *the author classified the starting and control equipment used in Naval vessels for d.c. motors. In the August, 1933, issue, following the introduction of alternating current machinery, he described the types of motors suitable for shipboard use. He proceeds now to sort out the manifold functions performed by starters and controllers for a.c. motors. Safety and protective devices are included in the classification. Materials are described.*

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The operating engineer is the principal beneficiary of this presentation. But the designing engineer will do well to have in mind a clear picture of the available control devices together with their applications.

In the perusal of the subject of this article, the technical reader and those associated with the operation of alternating-current motors, may be inclined to feel that the scope would permit only a brief uninteresting description of a conventional starter or controller as used by the commercial industries which in effect and application are generally the same as those used in the U. S. Navy.

The foregoing intimation of a narrow field of endeavor is engendered by the fact that nearly all of the alternating-current motors used for auxiliary power in the U. S. Navy, at the present writing, with the exception of an occasional wound-rotor induction motor or a synchronous motor, are of one general kind † known as the *squirrel-cage induction* type, electrical power to which is supplied by constant voltage, 60 cycle constant frequency, 3-phase alternating-current generators. The selection of this type of motor is influenced by its adaptation to simplified starting and control. This simplification, in general, consists of connecting the stator of the motor to the 3 wires of the three-phase power lines, either at full line voltage, or at reduced voltage followed by a full voltage connection. A device with such function would properly be termed a *starter*. The term *controller* for a squirrel-cage induction motor, can be applied only as a device for shifting line connections to obtain reversed rotation, or, to *select* one of several *basic* speeds where multi-speed induction motors are installed. (Commercially, two, three or four basic speeds are obtainable.)

Certain induction motors where speed *control* is required (regulated speeds lower than the basic speed), are known as *wound-rotor induction* motors, the speed control of which is obtained by external rheostatic adjustment of the secondary reactionary current developed in the rotor windings terminating in slip rings.

† *Alternating-Current Motors* by C. Huey. August, 1933, issue this JOURNAL.

From the above outline, one would conclude, and in effect it is practically true, that nearly all U. S. Navy single-speed motors are simply *switched* on or off the power lines, and the multi-speed motors (two or more basic speeds) are operated likewise at the selected speed, by simple switching. If they are *wound-rotor* induction motors, an additional rheostatic item is added to the rotor circuit for speed *control* (or regulation). These generalities indicate the basic simplicity of the subject. However, there remains much to be said concerning the way of getting the motors *properly* on the line, their protection from harmful overloads and short-circuits, phase failure protection, protection of the operator, limitation of in-rush currents in excess of the power-plant stability, the use of special materials for naval applications, schemes for suppressing the arcing at the switching contacts, low or under-voltage protection, low or under-voltage release, and suppression of heat and magnetic noises due to the use of alternating-current.

As might be expected, even where simplification has been the watchword in the selection of one basic type of motor for every application where practicable, the purchase specification for controllers for alternating-current motors for shipboard use, designated as Navy Department Specification 17-C-10a, to which we will now refer, lists and defines many classifications and types of controllers based on service conditions, control functions and general construction.

The class and type designations in which the various types of equipment are classified according to their principal design features are as follows:

(a) SERVICE CONDITIONS—With regard to the relative severity of the conditions under which they have to operate and/or their relative strategic importance:

NAVY A—Vital importance and/or severe conditions.

NAVY B—Lesser vital importance and/or more favorable conditions.

NAVY C—Importance and/or conditions similar to commercial applications.

(b) ELECTRICAL INSULATION—With respect to the temperature limits of the insulation employed in their construction:

Class A Insulation—Cotton, silk, paper, etc., limited to 105 degrees centigrade.

Class B Insulation—Mica, asbestos, etc., limits to 125 degrees centigrade (with binders).

Class C Insulation—Pure mica, porcelain, quartz, etc., higher temperature allowed but not specified.

(c) DEGREES OF ENCLOSURE—With respect to the use of coverings and the protection afforded:

Open—No enclosure required.

Semi-protected—Protection for devices mounted on the rear of the panel.

Protected—Whole controller protected.

Drip-proof—Protection to exclude falling solids or liquids.

Waterproof—Solid gasketed case, to withstand a specified water spray test.

Watertight—Solid gasketed case, to withstand a specified submergence test.

Explosion-proof—Enclosing case to withstand internal explosion of a specified gas without igniting external gas surrounding.

(d) SHOCK-PROOF CHARACTERISTICS—With reference to ability to withstand shock experienced on shipboard:

Class 150—Shock-proof—Withstand without damage or interruption of current, hammer blows of 150 foot-pounds intensity.

Class 50—Shock-proof—Withstand without damage or interruption of current, hammer blows of 50 foot-pounds intensity.

Class 25—Shock-proof—Withstand without damage or interruption of current, hammer blows of 25 foot-pounds intensity.

(e) CONTROL FUNCTIONS—With reference to control functions required by the motor installation:

Motor Starting—Basic function of starting and stopping the motor, including protection from overload and under voltage where required.

Motor Starting and Reversing—Basic function of starting and stopping the motor, wherein the direction of rotation of the motor is changed at the will of the operator.

Motor Starting and Speed Regulation—Basic function of starting and stopping the motor involving speed regulation or adjustment of motor speed as by rheostat control.

Motor Starting, Reversing and Speed Regulation—Basic function of starting, stopping or reversing the motor, involving speed regulation as by rheostat control.

Motor Starting and Speed Selection—Basic function of starting and stopping the motor, involving selection of one of several basic speeds as by pole changing.

Motor Starting, Reversing and Speed Selection— Basic function of starting, stopping, and reversing including selection of one of several basic speeds.

(f) TYPE OF CONSTRUCTION—With respect to general construction and method of starting and/or control:

Across-line Starter—Consists of a line switch (with protection as may be required) for throwing motors directly across the supply line. (Referred to also as "full-voltage starting.")

Starting Rheostat—Also referred to as the face-panel type. One whose stationary contacts are mounted upon the face of an insulating panel whose surface is a plane, the contacts being arranged in the form of an arc (or arcs) of a circle and the movable contact (or contacts) being mounted upon a pivoted switch arm (or arms).

Primary Resistor Starter—A starter which provides reduced voltage to the primary of the motor by inserting resistance in the primary circuit during acceleration. The device includes the necessary switching mechanism, which may be manually or magnetically operated.

Secondary Resistor Starter—A starter which reduces the primary starting current by inserting resistance in the secondary circuit (usually the rotor) of a wound rotor, during acceleration. The device includes the necessary

switching mechanism, which may be manually or magnetically operated.

Compensator (or Auto Starter)—A starter which provides for reduced-voltage starting by means of a compensator (or auto-transformer) from which a predetermined fractional part of the winding is tapped-off to produce the voltage reduction to suit the particular starting load. The device includes the necessary switching mechanism to shift from the tap to full voltage and also to open the circuit of the compensator winding.

Star-delta Starter—A star-delta starter is one which is applicable for starting motors which have their windings arranged for full rated operation with windings connected in delta and arranged for starting with windings connected in star or "Y."

Magnetic Controller—One wherein the main circuits are made and broken by magnetically operated switches controlled by a master switch located either within the controller or at any desired distance from the main controller.

(g) SUB-CLASSIFICATION OF MAGNETIC CONTROLLER—With respect to the operation of the control circuit:

Non-automatic—Where the operator is responsible for all control functions of starting, stopping and accelerating the motor.

Semi-automatic—Where the rate of acceleration after starting by the operator, is dependent upon accelerating contactors, which are adjusted to function under predetermined conditions of currents, voltages on time.

Full automatic—Where all basic functions, including starting or stopping of the motor, are performed without the necessity of manual direction in any degree after being initially energized.

(h) SUB-CLASSIFICATION OF MASTER SWITCHES—With respect to their type, for operating magnetic controllers:

Drum Switch—In general, for non-automatic types of controllers.

Push Button—In general, for semi-automatic types of controllers.

Automatic Switch—Operated by float, pressure, etc. For full automatic controllers.

Emergency Run Feature—Provides a means for temporarily rendering the overload device inoperative during an emergency.

(i) SUB-CLASSIFICATION OF MAGNETIC CONTROLLERS—With respect to the proximity of the master switch:

Distant Motor Control—Where the master switch is mounted apart from the main control panel.

Local Motor Control—Where the master switch may be combined with the main control panel.

(j) SERVICE CLASSIFICATION OF CONTROL RESISTORS—With reference to the duty period:

Continuous Rating—Where the load is required to be carried for an unlimited period.

Periodic Rating—Where the load can be carried for alternate periods of load and rest.

Standard Periodic Rating—Where the starting and intermittent duty may be standardized as light, heavy or extra heavy starting or/and intermittent duty classifications.

(k) KINDS OF PROTECTION—To be provided where required:

Low or Under-Voltage Protection—Operates to cause and maintain the interruption of the main power on reduction or failure of voltage.

Low or Under-Voltage Release—Operates to cause the interruption of power but not the reestablishment of power upon reduction or failure of voltage.

Overload Protection—Operates to protect against excessive current, to cause and maintain the interruption of current not in excess of six times the rated motor current.

Short-Circuit Protection—Where the overload protection does not provide for short-circuit protection, such short-circuit protection shall be provided, as by fuses.

Single-Phase Protection or Indication—Where required, shall indicate and protect the personnel and equipment upon the failure of any part of the circuit which would cause an open phase. In effect, this causes an open circuit in two phases.

The foregoing class and type designations outlined and defined by the purchase specifications, is extensive. It imparts the impression that what started out to be a simple subject, has now become complicated by the many divisions, sub-divisions and combinations conceivable in the listed designations.

Unfortunately, all these combinations are found, or are likely to be found, in Naval Service. However, to tear down this complication into a simple conception again, so that the shipmates of the a.c. controller may readily solve, at least, the basic principle involved in the starters or controllers likely to be found in Naval Service, the outstanding identification features to be expected from the functional standpoint, are covered in the following outline. It will be assumed in this outline that all motors are of the 3-phase induction type. The term *magnetic* is used to indicate the employment of an electrically energized device which operates magnetically to pull-in the switching contacts and/or to release the same.

(a) FULL-VOLTAGE OR ACROSS-THE-LINE STARTER, MANUAL, NON-REVERSING SINGLE SPEED (FIGURE 1a, AND PLATE A)—This device will have the conventional 3-pole, single-throw switch. The switch may perhaps be operated by a handle outside of the enclosing box and the switch may perhaps have a mechanical spring release for quick opening. The starter will have no starting resistors, reactors or auto-transformers. The motor will have 3 line wires only, and the rotor will have no slip rings or brushes. This will be the single-speed, squirrel-cage induction motor. (Incidentally, this is the prevailing type of motor up to approximately 30-horsepower rating.)

(b) REDUCED-VOLTAGE STARTER, MANUAL, NON-REVERSING SINGLE SPEED (FIGURES 1b AND 2a)—This device will have a conventional 3-pole, double-throw switch (starting and run-

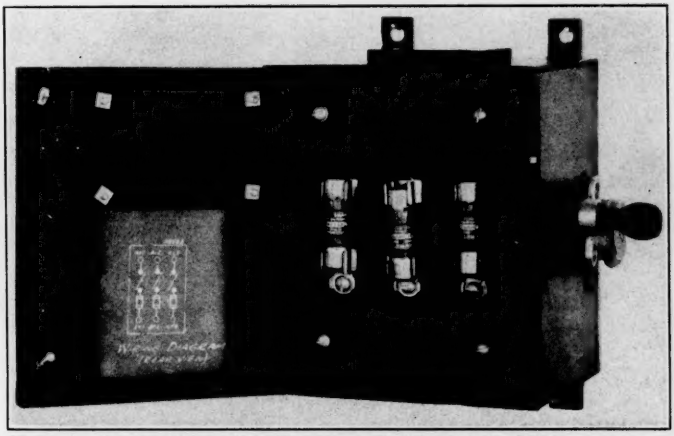


PLATE A.—SINGLE-SPEED, NON-REVERSIBLE, MANUAL, LINE-VOLTAGE STARTER.
(The switch is located behind the fuse-panel.)

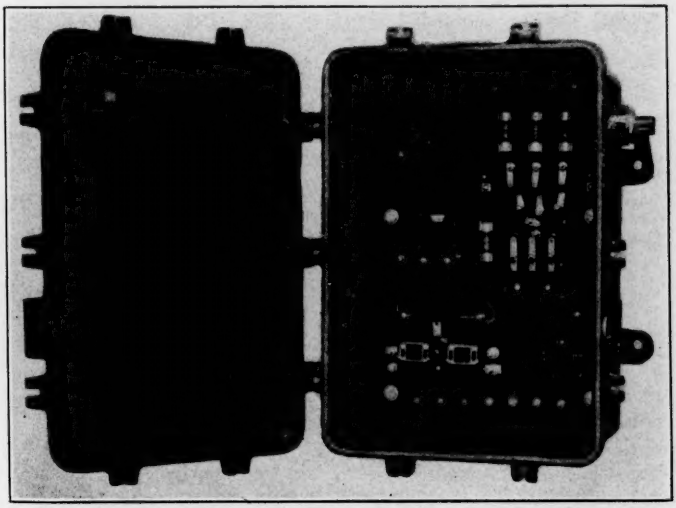


PLATE B.—SINGLE-SPEED, NON-REVERSIBLE, MAGNETIC, LINE-VOLTAGE STARTER.

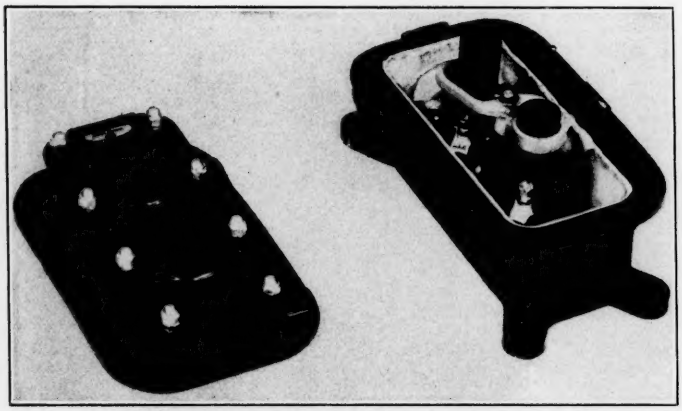


PLATE C.—LATCHED PUSH-BUTTON STATION.

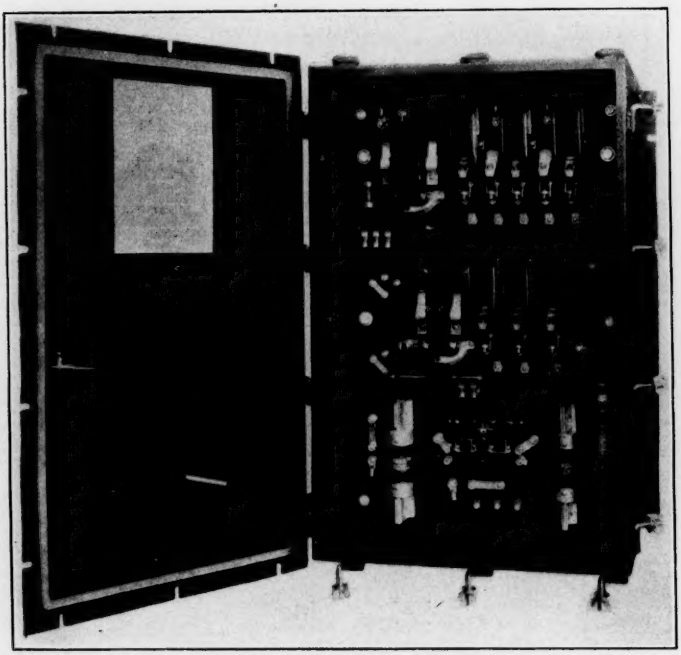


PLATE D.—SINGLE-SPEED, NON-REVERSIBLE, MAGNETIC, REDUCED-VOLTAGE AUTO-TRANSFORMER STARTER.

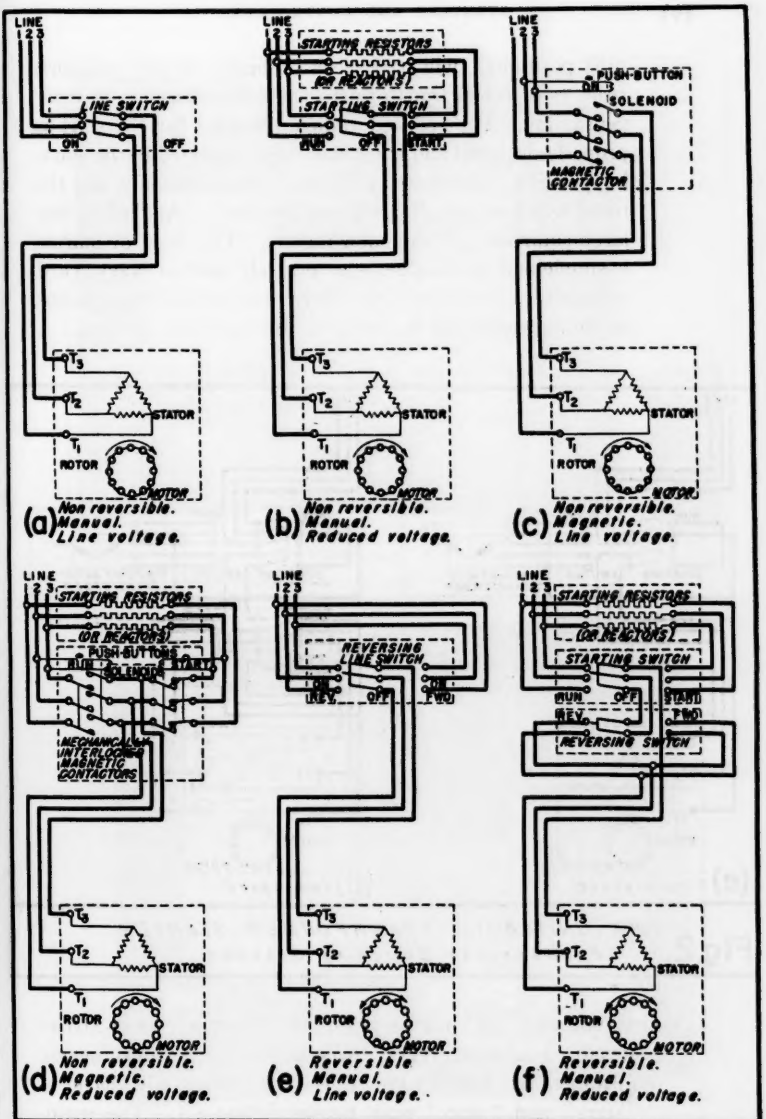


Fig. 1. SINGLE-SPEED INDUCTION MOTOR. Fundamental Starting Methods.

ning positions), will have a set of heavy current resistors, reactors or series transformers (auto-transformers or compensators). The reduced voltage obtained for the start is properly designed and is permanently connected to the starting position. The motor will have 3 line wires only, and the rotor will have no slip rings or brushes. (Applied to the large squirrel-cage induction motors. This type of starter is simple and practicable, is extensively used in Navy Yard industrial applications. Not likely to be found on shipboard as the magnetic type is preferred, for operating reasons.)

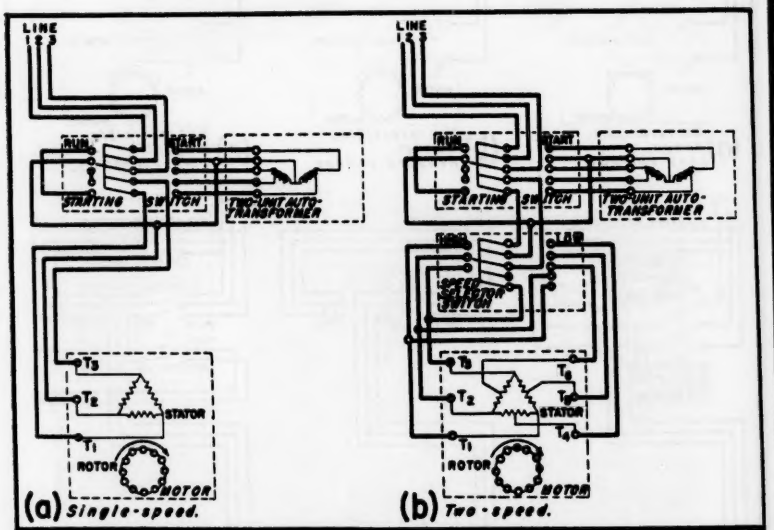


Fig. 2. TWO-UNIT AUTO-TRANSFORMER STARTER. Fundamental Switching Schemes.

(c) FULL-VOLTAGE OR ACROSS-THE-LINE STARTER, SEMI-AUTOMATIC, MAGNETIC TYPE, NON-REVERSING SINGLE SPEED (FIGURE 1c, AND PLATE B).—This device will have a "start" and "stop" push button (Plate C). The main control box will have a 3-pole magnetically operated contactor switch. The magnetic operating coils are energized

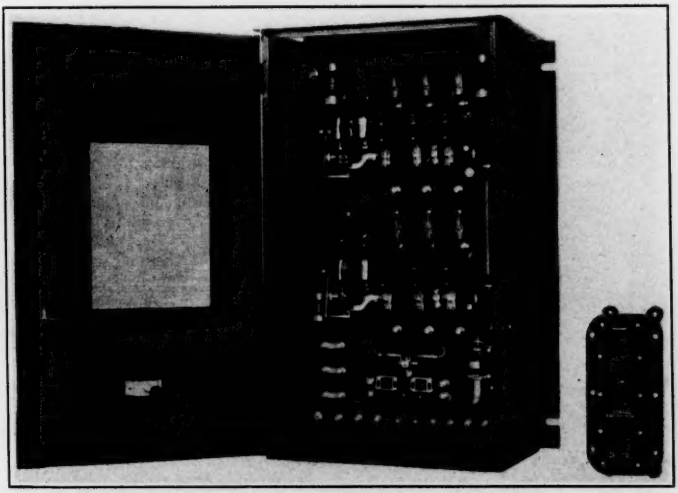


PLATE E.—SINGLE-SPEED, REVERSIBLE, MAGNETIC, LINE-VOLTAGE STARTER.

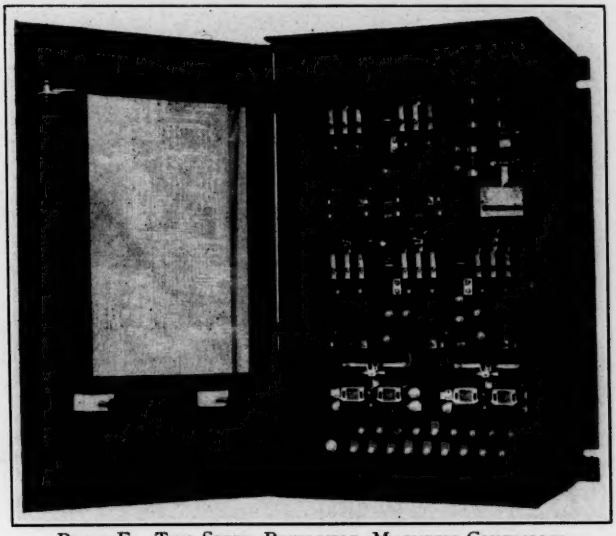


PLATE F.—TWO-SPEED, REVERSIBLE, MAGNETIC-CONTROLLER.

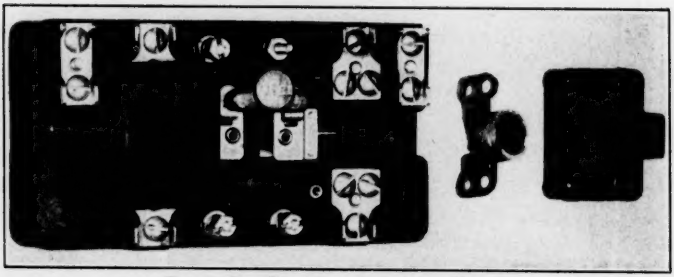


PLATE G.—THERMAL OVERLOAD RELAY.

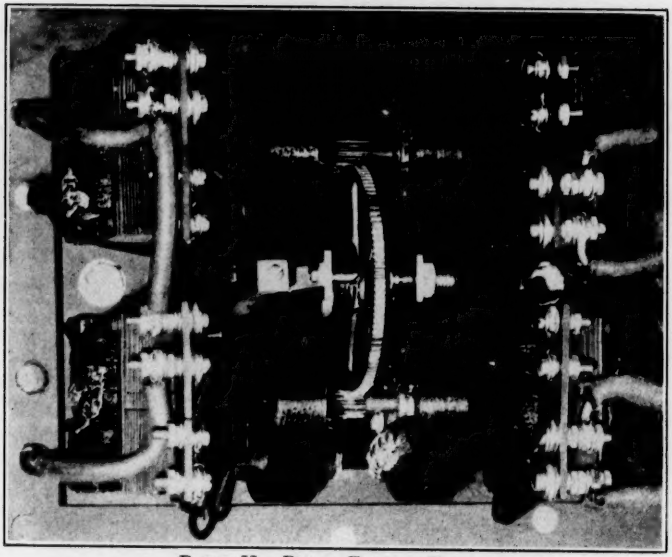


PLATE H.—PHASE-FAILURE RELAY.

from the line by a small exciting current when the control circuit is closed by the operator or an automatic device. The starter will have no starting resistors, reactors or auto-transformer. The motor will have 3 line wires only and the rotor will have no slip rings or brushes. (This is the prevailing type of starter for most of the small motors.)

(d) REDUCED-VOLTAGE STARTER, SEMI-AUTOMATIC MAGNETIC TYPE, NON-REVERSING SINGLE SPEED (FIGURE 1d, AND PLATE D)—This device will have the "start" and "stop" control for the operator similar to (c). The magnetic switching will be done by 2 sets of 3-pole contactors (one for reduced-voltage start and one for full-voltage running). The reduced voltage will be obtained by heavy current resistors, reactors or auto-transformers similar to (b). The motor will have 3 line wires only and the rotor will have no slip rings or brushes.

(e) REVERSIBLE DIRECTION OF ROTATION CONTROLLER, FULL-VOLTAGE OR REDUCED-VOLTAGE START, SINGLE SPEED (FIGURES 1e, 1f, AND PLATE E)—This device will have a hand-operated, double-throw, 3-pole main switch or two 3-pole magnetic contactor switches operated by push buttons or equivalent. One direction of switching will result in a definite phase rotation of the 3 line wires to the motor. The reversing action, or opposite rotation, is obtained by the switching connection, which interchanges 2 of the 3 line wires to the motor. If it is a *full-voltage* starter, it will have no resistors, reactors or auto-transformers, as in (a) and (c). If it is a reduced-voltage starter, it will have resistors, reactors or auto-transformers, as in (b) and (d). This, however, would require additional switching, and the complication of such switching added to the "reverse" switching makes the reduced-voltage application undesirable.

(f) MULTI-SPEED MOTOR STARTERS (OR CONTROLLERS) (FIGURE 3, AND PLATE F)—The multi-speed motors may have single or two distinct sets of windings. Combinations on the pole groupings result in different basic speeds. The pole groupings are accomplished by external regrouping on single and

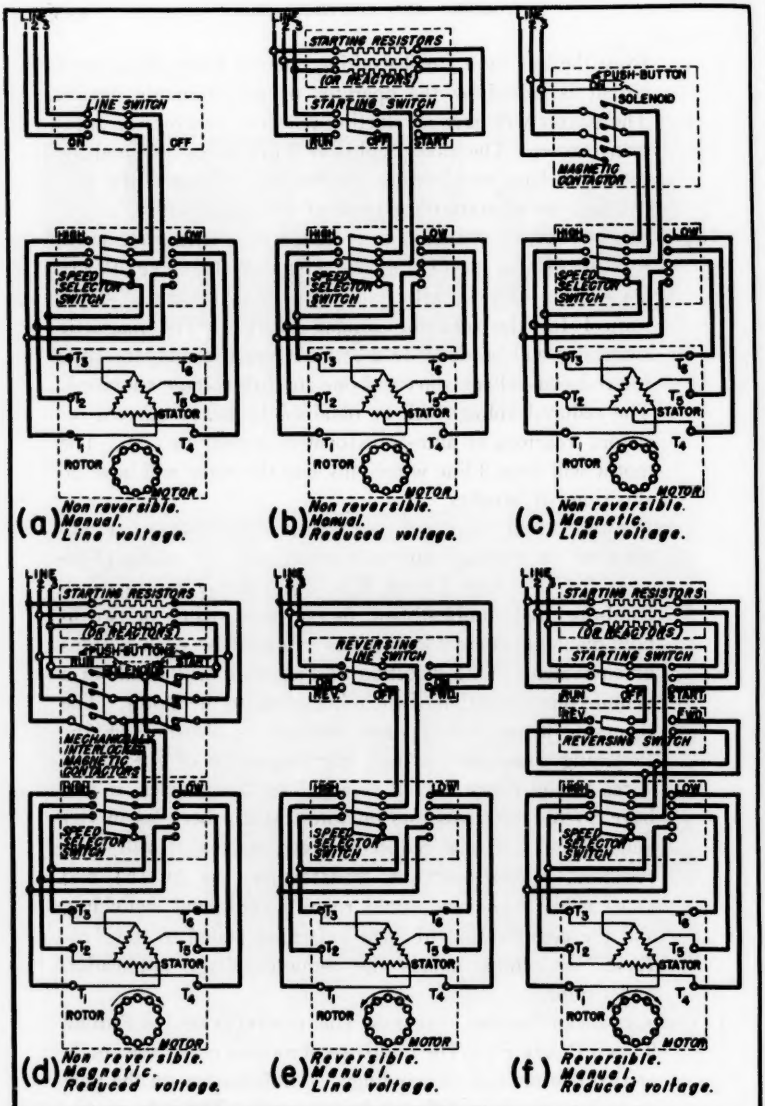


Fig. 3. TWO-SPEED INDUCTION MOTOR. Fundamental Starting Methods.

reconnection on double winding motors, so that the pole combination is obtained that is desired for the basic speed. The total number of turns of the windings remains the same in every case so that the same line voltage is applicable. The choice of basic speeds on a 60-cycle system is 3600 RPM (one pair of poles), 1800 RPM (two pairs of poles), 1200 RPM (three pairs of poles), 900 RPM (four pairs of poles), etc., but usually limited to four selections and actually in Naval Service the 2-speed (1800 and 1200) is the prevailing selection. The start can be made using any one of the basic speed connections and shift can be made at any time to any one of the other speed connections. Each speed requires a re-grouping or re-selection of the motor leads. The number of motor leads involved varies with the design of the motor. The starter may be of the full-voltage or reduced-voltage type, as in (a) and (b) or may be of the magnetic or non-magnetic type, as in (b) and (c), or may have the reversing arrangement, as in (e).

(g) STAR-DELTA REDUCED-VOLTAGE STARTER (FIGURE 4)—This device is associated only with motors *designed* for their full power with the "delta" connected 3-phase winding. There must also be provided additional leads from the motor which, when regrouped externally, will result in a "Star" arrangement of the 3-phase winding. There will be six main leads required from the motor to accomplish the switch from "Start," across-the-line ("star" connection), to "run," also across-the-line (delta connection). The effective starting voltage on the windings with the star connection based on vector relation of voltage is 57.7 per cent, as compared with the full voltage of the delta connection. This type of reduced-voltage starter, which is limited to 57.7 per cent by its fundamentals, can be used only where the motor has an *easy* starting load. For *hard* starting loads, the higher voltages obtainable with resistors, reactors or auto-transformers, in the order of 65 per cent to 85 per cent voltages, may be required. The starter may be of the magnetic or non-magnetic type. No resistors, reactors or auto-transformers are required.

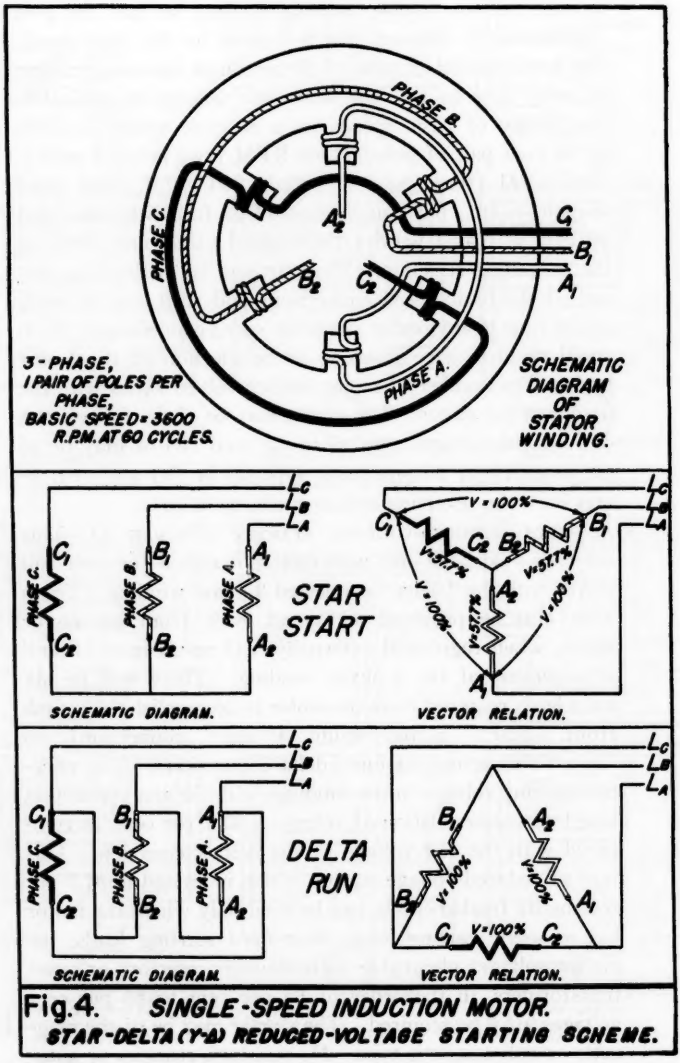
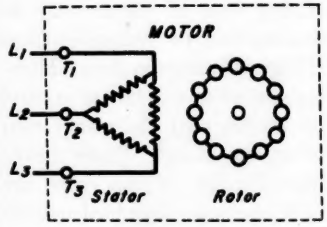


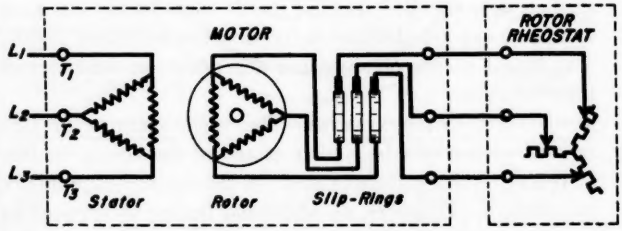
Fig.4. SINGLE-SPEED INDUCTION MOTOR.
STAR-DELTA (Y-Δ) REDUCED-VOLTAGE STARTING SCHEME.

(h) WOUND-ROTOR INDUCTION MOTOR STARTERS AND CONTROLLERS—The basic feature of this type of starter may be similar to any of the across-the-line or reduced-voltage starters used for the squirrel cage induction motors. However, an additional feature is required to regulate or control the current generated in the windings of the rotor when the power voltage is applied to the stator. Three heavy current leads from the collector rings of the *rotor* are brought to a 3-phase adjustable rheostat assembled usually as part of the starter, as shown in Figure 5b. Start is made at reduced line current and torque, with all resistance "in." Full power is obtained with all resistance cut "out." Intermediate or controlled speeds (speeds considerably less than synchronous) are obtained at intermediate resistance points. The actual speeds obtained are dependent on the external load demands.

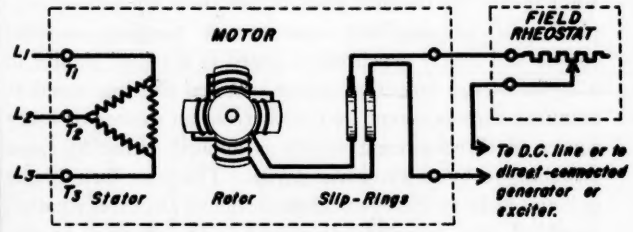
(i) SYNCHRONOUS MOTOR STARTER—The basic features of this type of starter may be similar to any of the across-the-line or reduced-voltage starters used for the squirrel-cage induction motors. However, an additional feature is required in connection with the *direct-current* excited rotor (see Figure 5c). The line *alternating current* power is applied to the *stator* with the circuit of the *direct-current* supply to the rotor open. As the field poles of the *rotor* are usually supplied with an auxiliary squirrel-cage winding, starting torque and nearly synchronous speed is obtained similar to a squirrel-cage induction motor. When the top speed is obtained, direct-current excitation from an exciter or other source of direct-current supply is applied, either by hand switching or by an automatic device. The rotor then "pulls in" and locks to the 60-cycle synchronous *electrical* rotation speed of the stator. Adjustment of a rheostat in the direct-current circuit, regulates the field strength of the rotor, which in turn controls the *power-factor* of the line current, but does not effect any change from the synchronous speed, unless the motor is overloaded. It is usual to adjust the field strength so that the line a.c. current is a minimum for the mechanical load. This minimum indicates unity power-factor has been obtained for the motor.



(a) Squirrel-Cage Induction Motor.



(b) Wound-Rotor Induction Motor.



(c) Synchronous Motor.

Fig.5. 3-PHASE A.C. MOTORS.
Fundamental Diagrams for Three Principal Types.

Protection from Harmful Overloads.

The problem of protecting a.c. motors from harmful overloads is different from that of the d.c. motors. This is due to the fact that where an a.c. motor is started at *full line* voltage, the in-rush current is usually 6 to 10 times the full load current rating. Where *reduced* voltage start is used, the in-rush current is usually 4 to 6 times the rating. These high currents, which decrease, but may be sustained from 3 to 10 seconds, are not only characteristic of the starting systems employed, but are necessary in order to develop the starting torques required. In a measure, it compensates for the poor starting torque which is the general characteristic of induction and synchronous motors.

In the case of *direct current,* it is the practice to start all motors of greater than fractional horsepower rating by multiple steps of reduced-voltage or current-limiting devices, which are designed to limit the in-rush current to 1½ to 2½ times the full load rating. This low order of current at the start, which produces sufficient torque, permits the use of enclosed fuses or magnetically operated overload circuit breakers in the main power lines, the rating or calibration of which can be low enough to protect the motor windings from harmful operating overloads as well as short circuits.

In the case of *alternating current,* the very much higher currents militate against the use of enclosed fuses for " harmful " overloads. In fact, the fuses are of necessity required to be rated so high for the starting current that, when and if used, they serve to protect the motor and leads only from *short circuits.* The windings of the motor may well be expected to burn out from an excessive power demand or stalled condition, without causing the line fuses to operate. The same analogy exists for the magnetic circuit breaker, unless time-delay devices are incorporated. If time-delay devices were to be employed on a normal size circuit breaker, then the time delay would militate against a quick release in the event of a short circuit.

Recognizing the foregoing problems of protection and the limitations of direct-current schemes, it is the prevailing practice to incorporate on a.c. starters a device known as the *thermal overload release* (see Plate G). This device is relatively small and may

consist of an induction heater or a few turns of heater wire, inserted in the main-current circuit. A bimetallic strip is arranged in the coil so that it will flex with the heat produced. This, in turn, operates to open the energizing circuit of magnetic circuit breakers in the main line.

The thermal lag of the device in combination with the heater element is designed for each specific installation so that it "holds in" while the motor starts successfully with its load. The thermal release then further serves to open the circuit when harmful operating overloads are experienced. The *time* of opening is approximately inversely proportional to the magnitude of the overload.

Protection from Short Circuits.

It is obvious that with the use of a time-delay thermal release, which satisfactorily solves the problem of harmful overloads, the incorporated time delay is unsuitable in its protection from *short circuits*. For this protection, recourse is had to fuses enclosed in three main lines, the rating of which is sufficiently high to withstand the starting current. In instances where the fuses fail to hold the starting current and where it is known that no ground leakage or short circuits exist and where space limitations or fuse clip centers prevent the use of higher-rated fuses, recourse is sometimes had to "time-lag" enclosed fuses. These fuses look like the conventional fuse and operate on the overloads and short circuits in the same way. The fuse element, however, is thermally weighted to increase greatly the time lag only, but not change its operating rating.

Phase Failure Protection.

The problem of phase failure protection arises from one of the adverse features in the use of three-phase a.c. motors operating from a 3-wire power system as employed in the U. S. Navy, and in general use commercially. Theoretically and practically, three-phase power can be generated and can be distributed, using 6 wires (2 wires per phase), each phase being a separate circuit. Upon the failure of any one of the six wires or of two wires of one phase, the motors can start and be operated at reduced power with the full normal torque of two phases.

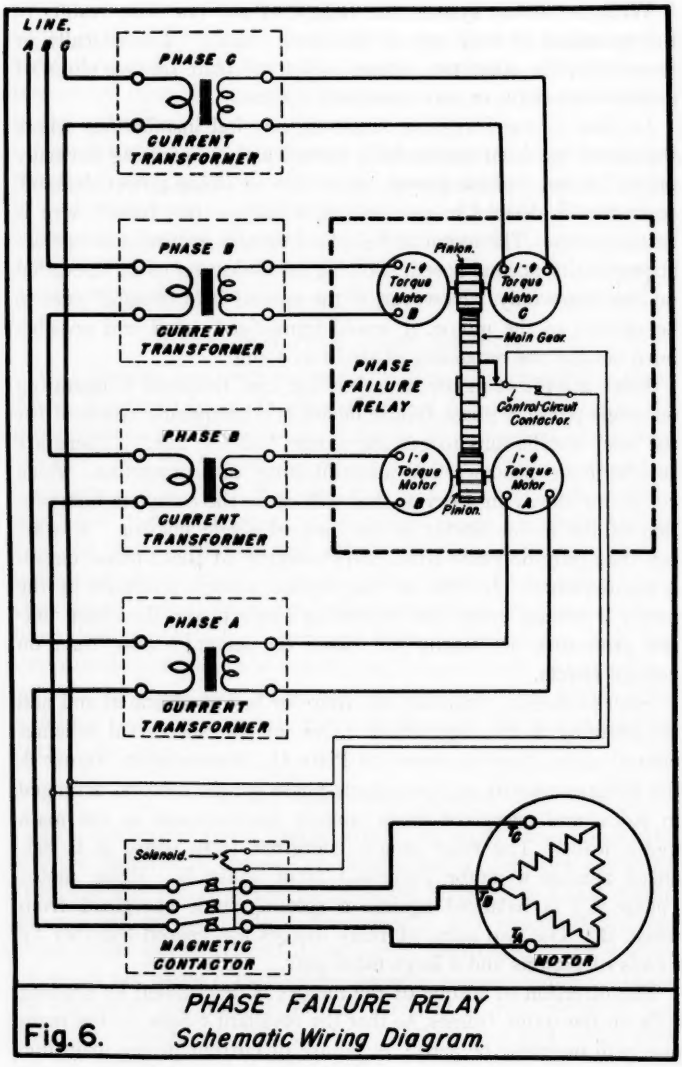
With the 3-wire system, the failure of any one wire results in the operation of only *one* of the three phases. Theoretically or practically, the other two phases cannot circulate on two wires of a three-wire delta or star-connected system.

In view of the foregoing situation, on vital installations where the motor has been successfully started and is operating normally on its 3-wire, 3-phase power, but at low or idling power demand, protection is desired in case one fuse fails or one feeder wire is carried away. The motor at light load usually continues to operate at practically normal speed, showing no indication of its operation on one phase only. However, if the normal load demand were to be applied to the motor, it would immediately stall and possibly burn out the one remaining phase in so doing.

Since a 3-phase motor is useless for load demands if operating on single phase, a phase failure device is consequently required for the vital installations to get the motor "off the line." There are several basic schemes for accomplishing this protection, which consist primarily in a device that will cause the complete interruption of the motor circuit at the time of single phasing. Restart can then only be made when the continuity of the 3-phase circuit is reestablished. In view of the counter voltage produced by the motor windings, even when operating single phase, the phase failure protectors necessarily are based on current rather than on voltage effects.

Such protectors, however, are more or less complicated and add considerably to the equipment. One of the successful schemes offered to the Navy is shown on Plate H. Referring to Figure 6, the scheme consists of four single-phase torque motors, arranged in pairs, and energized from current transformers in the main motor leads. The relay motor, energized from phase A is balanced against a motor energized from phase B. Relay motor (phase C) is balanced against a second motor energized from phase B. The two pairs of relay motors are geared together by means of pinions and a large main gear.

The direction of torque of the motors is determined by shading coils on the stator frames, so that the resultant torque on the main gear will normally be zero. A failure of current in one main line will, however, upset the balance and cause the gear to turn. After



PHASE FAILURE RELAY

Fig. 6. Schematic Wiring Diagram.

a certain angular movement of the gear, mechanical devices cause a set of contacts to open. This, in turn, interrupts the *control* circuit of the main line magnetic switches. Provisions are made for manually restoring the mechanism to its original balance upon return of the 3-phase power.

Protection of the Operator.

Schemes for protection of the operator necessarily have been given considerable attention from the earliest days, when 80-volt direct current was the operating voltage of Navy Auxiliaries. However, voltages of this magnitude (to be increased in later days to 115 and 230 volts) were considered to be insufficient to cause more than an unpleasant "jolt" if the operator willingly or unwillingly came in contact with both sides of the line, or one side of the line if the opposite side happened to be grounded. Protection of the operator for these relatively low voltages did not progress much beyond the point of using adequately insulated handles for switches and circuit breakers. Insulated push buttons operating at line voltage were used for distant control circuits.

With the advent of 440 volts alternating current into the newer Navy, the problem has become much more serious. Even a change from d.c. to a.c. increases the voltage hazard by the factor 1.41. This factor takes into account the maximum or peak voltage of a sine-wave a.c. current. It is the peak voltage which the operator would "feel" and not the effective or operating voltage. If the Navy voltage were to be 440 d.c., the operator would "feel" 440 volts. When it is 440 a.c., the operator would "feel" 440×1.41 or 620 volts. Therefore, so far as the hazard is concerned, the newer Navy is operating at 620 volts. This is important to remember at all times, as power voltage of this magnitude has a heavy "kick," and if it is sustained or firmly grasped, a casualty is to be expected. The seriousness of the casualty would be affected by the physical reaction of the recipient, the path of the current and moisture conditions.

In view of the foregoing, the necessity for adequate protection to the operator of the 440 a.c. ships is recognized. The desire for protection has developed the following requirements:

(a) The use of "dead front" switchboards where every device including switch blades, bus bars, fuse clips, etc., are behind insulating cover plates.
(b) No exposed terminals on the motors.
(c) Hand-operated, semi-automatic or automatic motor starters or controllers, fully enclosed, bolted shut or padlocked.
(d) Control handles, where used, operated externally without opening the box.
(e) Push-button start and stop devices which operate in the control circuit, energized by small transformers supplied with the equipment which reduce the voltage from 440 to 110 volts or less.
(f) Electrically operated door latches on enclosing boxes which prevent the operator from examining or touching the interior of starters or controls unless the *feeders* to the box are deenergized (see Plate J).

Limitation of In-rush Current in Excess of the Power Plant Stability.

The preceding generalities of the various methods of reduced-voltage starting are, of course, based on the desire to limit the in-rush current from the power lines. This, in turn, ties in with the desire to reduce to a practical value the demands from the generators of the power plant.

The inherent voltage regulations of all alternating-current generators are of a very low order. When the current demand is relatively high, as compared with the capacity of the plant, the normal line voltage is maintained only by a very large variation in the field excitation of the generators. It is always the problem of the designers of the power installations to determine the limits of in-rush current to the motors. From a mechanical and electrical standpoint, it is practicable to start any 3-phase induction or synchronous motor at full voltage or across-the-line, regardless of the size. The in-rush current, therefore, is limited by the stability of the power plant in regard to its effect on other power motors or lighting circuits and control devices.

Not knowing the actual in-rush currents of various brands and types of motors in advance of purchase, it is the practice in the

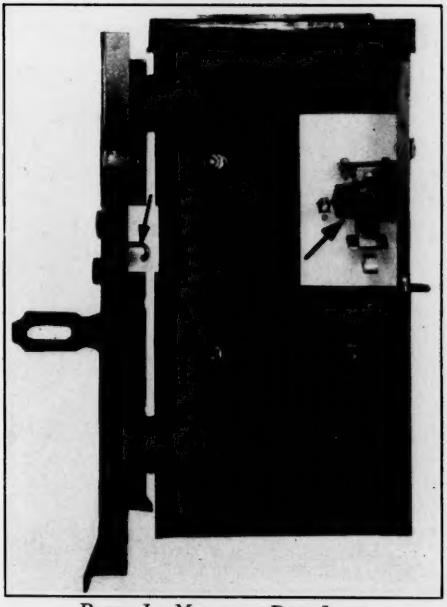


PLATE J.—MAGNETIC DOOR-LOCK.

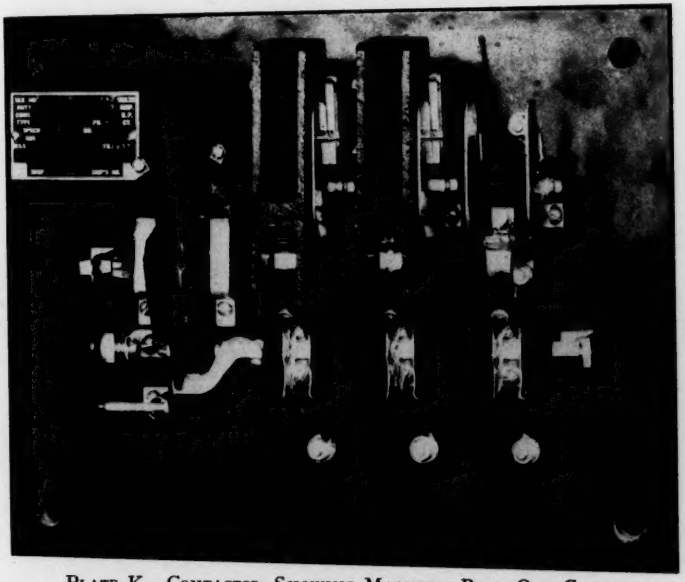


PLATE K.—CONTACTOR, SHOWING MAGNETIC BLOW-OUT COILS.

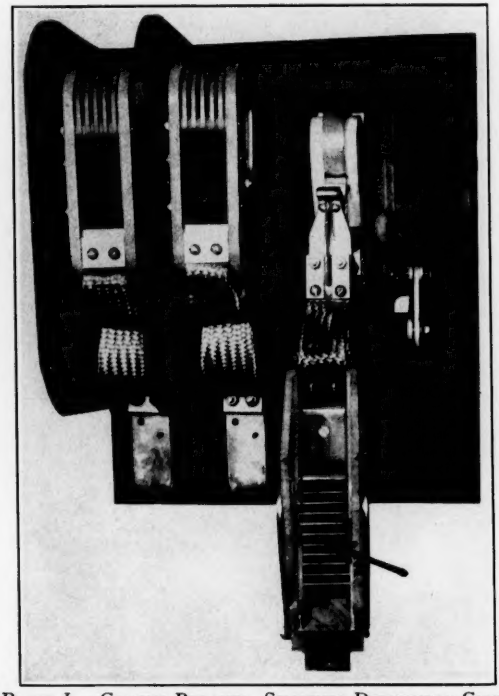


PLATE L.—CIRCUIT-BREAKER, SHOWING DEIONIZING GRIDS.

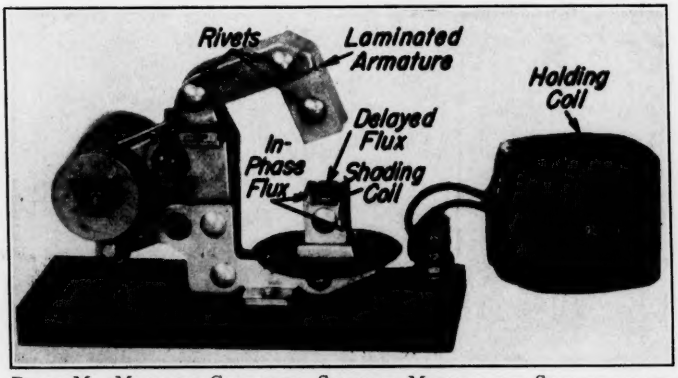


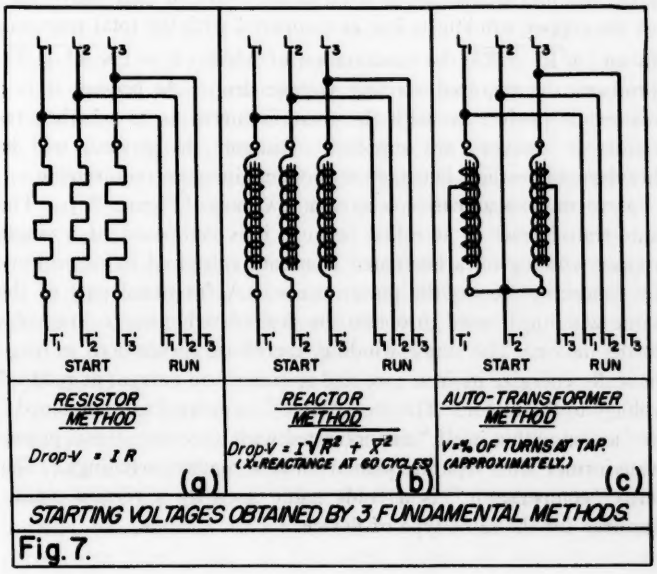
PLATE M.—MAGNETIC-CONTACTOR, SHOWING METHODS FOR SUPPRESSION OF HEAT AND MAGNETIC NOISES.

Navy as well as in industrial installations, to make the permissible limit of full-voltage start, in terms of horsepower rating of the motor. This is rather a poor "yardstick," but it is a practical unit and it at least fixes some basis of control. The limit at present is somewhat indefinite, but it may be considered, in general, to range from 5 HP to 30 HP, depending on the specific type of ship.

The present-day method of limiting the in-rush current consists in applying a reduced voltage to the motor by means of one of the several reduced-voltage starting devices, of which are available the following:

Series resistors
Series reactors
Auto-transformers (or compensators)
Star-Delta re-connection.

SERIES RESISTOR METHOD (Figure 7a). In this method the resistors are usually in the form of bare resistance wire or ribbon, wound helically on a fireproof core for the smaller motors, and



STARTING VOLTAGES OBTAINED BY 3 FUNDAMENTAL METHODS.

Fig. 7.

may be of the resistance grid type for the larger motors. The ohmic resistance of the resistor is designed to reduce the line voltage to such a value that sufficient current is obtained in the motor for its torque requirements. A resistor is used in each leg of the three main leads and it is not usual to provide any ready adjustment of the amount of active resistance. The current-carrying capacity of the resistor is designed to provide for the specific application in terms of starting load and frequency of starting duty. Only one step of starting resistance is usual. Ample provisions are made to provide for radiation of the considerable heat generated in the resistors during the start.

SERIES REACTOR METHOD (Figure 7b). In this method one reactor unit is likewise used in series with each of the three main leads. The unit is designed to give a voltage drop *equivalent* to a resistor. This, however, is not obtained by the use of resistance material as with resistors, but consists of a winding of insulated *copper* wire on a laminated iron core, which results, when using 60 cycles a.c., of an impedance or a.c. voltage loss. There is relatively little heat loss in the reactor unit, as the ohmic or heat factor (R) of the copper winding is low as compared with the total reactance factor ($\sqrt{R^2 + X^2}$) the combination of which ($V = I\sqrt{R^2 + X^2}$) produces the required starting voltage drop. At present it is a matter of preference with the manufacturers as to whether resistors or reactors are supplied. Reactors, in general, will be heavier and costlier, but more economical in space requirements.

AUTO-TRANSFORMERS (OR COMPENSATORS) (Figure 7c). The auto-transformer is so-called because it is composed of a single copper winding on a laminated iron core energized in its entirety by connection across the power mains. A fractional part of the same winding is used to obtain the desired reduction in line volts to the motor. The single winding, therefore, serves both to magnetically energize its iron core and to transform current at reduced voltage to the motor. The term "auto" is defined as "combined" or "action within itself," as contrasted with the conventional power transformer with separate primary and secondary windings. The term "compensator" is a trade name used by a certain manufacturer for the same type of device.

It is usual to supply only two auto-transformers, which are connected in the circuit as shown in Figure 7c. The use of two, in lieu of three units, is for economical reasons, as even when using two units numerous switching contacts are required (as shown in Figure 2) to connect and disconnect the magnetizing and the power currents of the units for the start and running positions. The use of three units, however, produces balanced currents in the three main leads, whereas, with two units there will exist approximately 15 per cent higher current in the third leg, which in some instances may be objectionable. The chief advantages of the auto-transformers are low heat losses and ready adaptability of raising or lowering the starting voltages by changing the taps provided for on the units. This usually permits 65 to 85 per cent voltage selection to suit the specific motor application.

STAR-DELTA RE-CONNECTION. This is a scheme of obtaining a reduced-voltage start without the use of resistors, reactors or auto-transformers. It is done by a scheme of re-connection of the stator windings of the motor as shown in Figure 4. The use of this scheme is predicated on the motor being designed to deliver its horsepower rating when it is *delta* connected. If the motor were to be designed for its rating when *star* connected, which is said to be the commercial practice for economical winding reasons, the star-delta scheme of start would not be applicable. As established by the vector relationship and as indicated in the diagrams, the effective voltage on each phase of the windings when star connected is 57.7 per cent, as compared to 100 per cent voltage when re-connected delta.

The advantage of this system is that there are no heat losses in the starting devices for the reason that full-line voltage is applied to both the start and running positions. It is, therefore, economical in space requirements. The scheme, however, is limited to special applications where 57.7 per cent starting voltage is sufficient, such as for welding sets and other forms of motor-generators. The disadvantages are that for motors starting under mechanical load, the 57.7 per cent voltage may be insufficient and there is no means presented for increasing it. Also, to re-connect the motor from star to delta, ten terminal leads are required from the motor, as compared with three leads in the other forms of reduced-voltage starters.

Use of Special Materials.

The use of special materials in the design of starters and controllers for Naval Service which would have properties of withstanding high and low ambient temperatures, salt atmospheres, shock and vibration, is naturally to be assumed. However, on the whole, the use of special materials for Naval Service is not particularly marked. In general, any design which incorporates the best engineering practice, which would be reliable in public service or in high-grade commercial industries, would parallel the present requirements of the Naval Service.

Phenolic materials, either molded or laminated, are being used extensively for small panels, enclosing boxes, cover plates, magnet spools, switch handles, push buttons, interlocks, lamp sockets, instrument cases, etc. Weight is saved and ample strength is obtained, in addition to the high electrical properties inherent in phenolics.

The use of refined silver is increasing for relay contacts and main-circuit contactors. Copper for these purposes is rapidly being discarded, due to its ready oxidation under heat and moisture. Laminated copper, silver-plated copper and wiping-cast copper contacts are still to be found, but mostly in manually operated switching devices.

The virtues of silver are found in its yielding surface, resistance to oxidation, high current capacity and the important property of maintaining a constant low contact loss under most operating conditions.

Cadmium plating is being extensively used for the protection from corrosion of nuts, screws, bolts, washers and other mechanical pieces. Stainless steel is being used for mechanical wearing parts such as rollers, cams, shaft pins, etc. Arc barriers are necessarily made of material which will not carbonize under the intense heat of the rupturing arc. Asbestos, compounded with inert fillers, formed or pressed into a hard surface, is the chief material being used at present for arc barriers.

Magnet core windings for operating relays, contactor switches and other electro-magnetic devices are insulated by quite a variety of materials, including asbestos, glass fabric, cotton, silk, enamel, varnished cambric, mica, etc.

Moisture resistant impregnating compounds are applied by the various commercial processes to thoroughly insulate coil windings under all operating conditions of heat, moisture, vibration and shock.

Resistance materials, where used to reduce voltages on holding coils or as starting resistors, are required to be of corrosion-resistant alloys of low-temperature coefficient and to be non-oxidizing under operating temperatures. Nickel-chromium-iron alloys in various grades, in the form of wire or ribbon, are the prevailing materials for this purpose.

Suppression of Arcing at the Contacts.

The problem of suppression of arcing at the contacts is one which, in the main, is the responsibility of the supplier. The requirements of the Navy are generally in terms of specified duty performance and load rating. Alternating current is particularly favorable, as compared with direct current, in the suppression of arcing. As each sine wave of the a.c. power current passes through the zero point (120 times per second on 60-cycle current), conditions are favorable at each point for the natural suppression or interruption of any arcing which may be created upon opening of a current circuit.

However, there are limits, even with alternating current, where special devices need to be incorporated to suppress arcing quickly before the contacts are damaged to any visible degree.

Relay contacts which break only very small currents, but still may show undesirable arcing due to an induction circuit, usually have condensors of suitable capacity wired in parallel across the contacts.

Load contacts of manually operated switches usually have no special means of suppressing the arc, other than sufficient air gap distances and possibly a mechanical device for obtaining quick break.

For magnetically operated switches (or contactors) it is usual not to provide any special means for suppressing the arc for ratings not exceeding approximately 50 amperes at 440 volts. For ratings of 200 to 400 amperes it is usual to supply a magnetic blow-out coil at each contact energized by the line current with which it is in series (see Plate K).

For ratings above 600 amperes it is customary, in addition to magnetic blow-outs, to supply a *secondary* contact break and an arcing horn from which the arc is magnetically expelled. In addition to the foregoing devices, for magnetically operated switches or contactors, where short-circuit currents of very high order are provided for, it is customary to add an arc-chute over the contacts, in which is incorporated a scheme for breaking up the arc by de-ionization and magnetic propulsion (see Plate L).

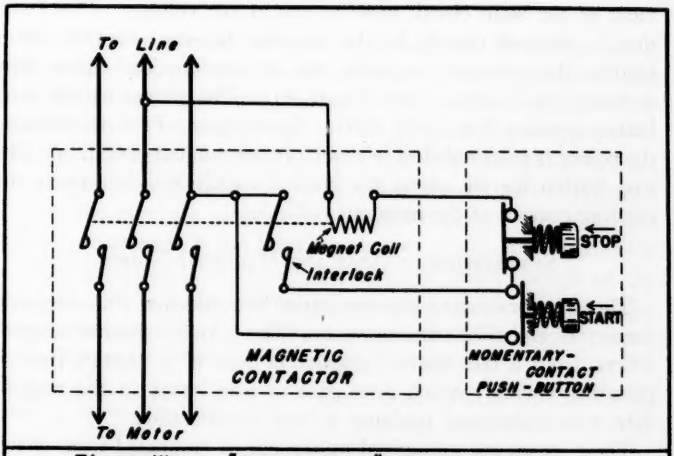
Low or Under-Voltage Protection.

This form of protection consists of a device, operative on the reduction or failure of line voltage, to cause and maintain the interruption of power to the motor until restarted by the operator. The most common form of this device for magnetic controllers is the so-called *three-wire* control circuit in combination with a start and stop push button (see Figure 8). The circuit requires an auxiliary control-circuit contact on the main contactor, which acts as a maintaining circuit for the contactor magnetic coil. The start button is normally open. Low voltage or failure drops out the main contactor, thereby also opening the auxiliary contact attached to it and thus preventing the contactor from again picking up on the return of the line voltage. Manual momentary operation of the start button of the three-wire control circuit bridges the auxiliary contact circuit to energize again the contactor holding coil. The start button again stays open and the circuit is maintained by the auxiliary contacts on the main contactor. The stop button merely opens the control circuit, which allows the main contactor to drop out.

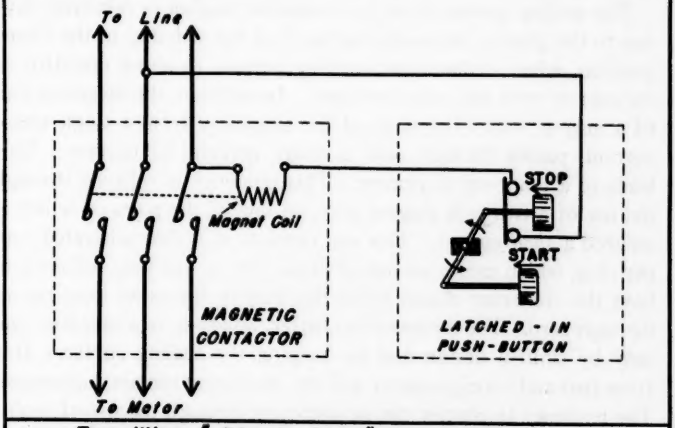
Where the controller is manually operated, a voltage-release coil is provided, which trips a mechanical latch on the contactor when the coil is de-energized from voltage failure. Upon return of the voltage, the contactor may be relatched for a new start. A disc induction-type time-delay device is also used, adjustable for both time delay and voltage at which the release may occur.

Low or Under-Voltage Release.

This form of protection consists of a device, operative on the reduction or failure of line voltage, to cause the interruption of power to the motor, but not to prevent the automatic re-establish-



Three-Wire "Start-Stop" Push-Button
LOW OR UNDER VOLTAGE PROTECTION.
Fig. 8.



Two-Wire "Start-Stop" Push-Button
LOW OR UNDER VOLTAGE RELEASE.
Fig. 9.

ment of the main circuit upon return of the voltage. This function is obtained usually by the so-called *two-wire* control circuit feeding the contactor magnetic coil, in combination with a start and stop push button (see Figure 9). The contact of the start button remains closed after start. Upon return of the line voltage, the power is re-established without further manual operation. The stop button merely opens the control circuit and interrupts the exciting current of the magnetic coil.

Suppression of Heat and Magnetic Noises.

These factors come into prominence in connection with magnetic contactors and relays for a.c. controllers. An a.c. excited magnet differs from a d.c. excited magnet in that it is excited from a pulsating current, which gives rise to iron losses in the magnet core, with consequent tendency to heat considerably.

These losses are minimized by the use of laminated iron, which breaks up induced eddy-currents and thus reduces the heating of the magnet core. Tendency to "hum" is suppressed by suitable riveting or clamping of the laminations (see Plate M).

The sealing power of an a.c. contactor magnet is relatively low, due to the greatly increased reactance of the winding in the closed position, which reduces the exciting current to about one-fifth of the current with the contactor open. In addition, the magnetic flux of a magnet which is energized for simplicity from a single-phase current, passes through zero at every reversal of current. This leads to a tendency to chatter. This tendency is relieved through the use of a two-pole magnet core, on one of the poles of which is secured a *shading* coil. This coil consists of a short-circuited copper ring, which causes an out-of-phase flux in one pole sufficient to hold the contactor closed while the flux in the other pole passes through zero. The tendency to chatter, however, is a problem, and only by skillful design and by keeping the sealing surfaces free from rust and foreign matter will the chattering remain suppressed. The tendency to chatter can be overcome through the use of multiphase magnet coils, but the additional complication makes this prohibitive.

Conclusion.

The foregoing must of necessity be limited only to fundamentals, with the addition of a few representative practical applications and a brief description of the general purpose of the various component parts. To elaborate and do full justice to the subject, or to describe the many diversified types of complete assemblies or component parts designed by the various suppliers of Navy apparatus to meet the purchase specifications, would require a very extended article. In general, it has been the purpose of this article not only to show the essential difference between the direct current of the older Navy * and the alternating current control system of the newer Navy, but to give sufficient generalities to be helpful to the operating personnel of the alternating current ships.

* See Journal of the A. S. N. E. of November, 1925—*Starters and Controllers for Navy D.C. Motors*, by C. Huey.

THE EFFECT OF TIME AND ELEVATED TEMPERATURES ON NAVAL BOILER TUBING.

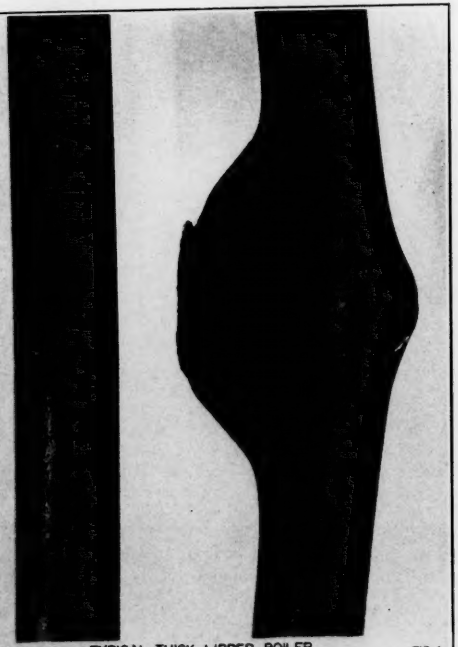
By Lieutenant Commander A. P. Calvert, U. S. N., Member.

The author presented an authoritative paper, "Factors Influencing the Failure of Naval Boiler Tubes," in the February, 1939, issue of the Journal. *He extends the results of his investigations here by reporting laboratory tests of boiler tubing under pressure at elevated temperatures.*

Introduction.

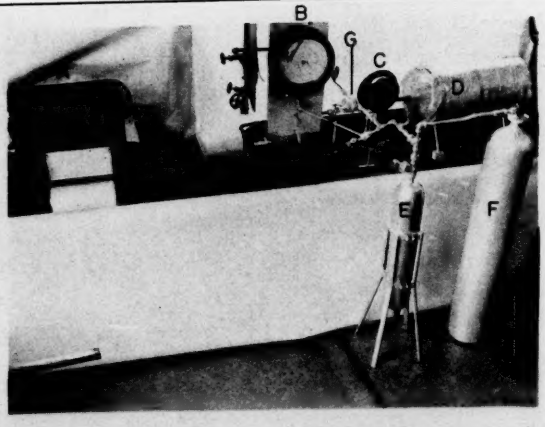
A considerable amount of research has been done in the investigation of the behavior of carbon and alloy steels at elevated temperatures by those interested in the problems of the power plant and by oil refinery operators. Such test work has evolved much information of great value, particularly to users of steel tubing which must withstand pressures up to 1200 pounds per square inch and temperatures as high as 1250 degrees F. for long periods.

One might ask what could be the Navy's interest in a boiler tube material capable of being used under the above conditions when the pressures and temperatures in existing naval boilers are so much lower than the above figures. The answer is found in the fact that failed naval boiler tubes received at the U. S. Naval Engineering Experiment Station, when examined under the microscope in the polished and etched condition, indicate that the metal temperature has exceeded 1600 degrees F. in some cases. Visual examination of typical ruptured tubes discloses the conditions noted in Figure 1. There appears to be little thinning of the tube wall, and no waterside scale is present near the opening. The presence of the network of discontinuous lines commented on by this writer in a previous paper [1] are plainly visible. The rupture faced away from the furnace in a typical "A" type express boiler.



TYPICAL THICK LIPPED BOILER TUBE RUPTURE.

FIG. 1



A- TEMPERATURE CONTROLLER & RECORDER.
B- PRESSURE RECORDER.
C- " GAUGE.
D- ELECTRIC FURNACE CONTAINING TEST SPECIMEN.
E- AIR BOTTLE.
F- CO_2 BOTTLE.
G- WATER COOLED END OF TEST SPECIMEN SHOWING METHOD OF CONNECTING THERMO-COUPLE LEADS.

FIG. 2

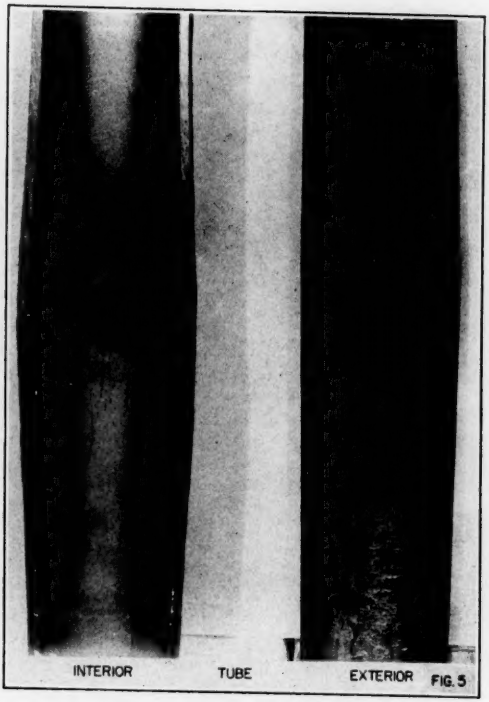


FIG. 5

The following is a summary of an investigation intended to throw more light on several questions:

(1) Do boiler tubes under ordinary operating pressures fail at metal temperatures up to 1800 degrees F. due to internal or external heat corrosion or is the primary cause plastic flow or "creep"?

(2) At elevated temperatures and for short periods of time, is oxidation of the tube metal more destructive than at lower temperatures for longer periods?

(3) How long can a boiler tube stressed solely by internal pressure resist rupture at elevated temperatures?

Test Apparatus.

The test set-up for this investigation is illustrated in Figures 2 and 3 and, while of a simple nature, was beset with many interruptions due to the high temperatures used, before successful runs

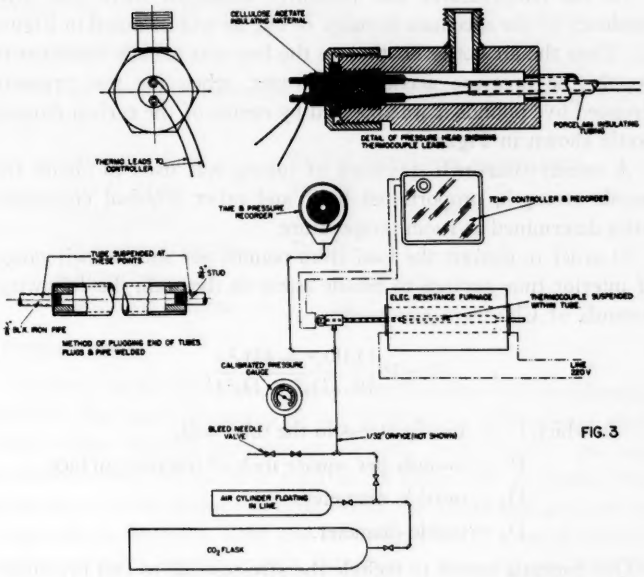

CELLULOSE ACETATE INSULATING MATERIAL
DETAIL OF PRESSURE HEAD SHOWING THERMOCOUPLE LEADS
PORCELAIN INSULATING TUBING
THERMO LEADS TO CONTROLLER
TIME & PRESSURE RECORDER
TEMP CONTROLLER & RECORDER
TUBE SUSPENDED AT THESE POINTS
STUD
BLK IRON PIPE
METHOD OF PLUGGING END OF TUBES PLUGS & PIPE WELDED
ELEC RESISTANCE FURNACE
THERMOCOUPLE SUSPENDED WITHIN TUBE
LINE 220 V
CALIBRATED PRESSURE GAUGE
BLEED NEEDLE VALVE
1/32" ORIFICE (NOT SHOWN)
AIR CYLINDER FLOATING IN LINE
CO_2 FLASK

FIG. 3

could be completed. The apparatus is somewhat similar in design to that employed by White and Clark,[2] though the test temperatures used by them were not as high as those described herein.

The test specimens used were eighteen-inch long sections of one-and-one-half-inch outside diameter boiler tubing with an average wall thickness of .126 inch, and were purchased under current Navy Department Specifications.

For each run the electric furnace was stabilized at the desired temperature, the water cooling started and the boiler tube section was then subjected to the test pressure by means of an air bottle. At this time the test was begun, and was considered ended when actual rupture had taken place.

Some difficulty was encountered in maintaining pressure-tight the end cap outside the furnace, this being solved by bringing the thermocouple leads out through spark plugs and water cooling of the end cap.

At the temperatures and pressures employed there was little tendency of the specimen to bulge or bag as will be noted in Figure 5. Thus the air bottle floating on the line was usually sufficient to supply the pressure needed. However, when the test pressure dropped five pounds it was boosted by means of the carbon dioxide bottle shown in Figure 2.

A twenty-four-inch specimen of tubing was used to obtain the tensile strength, proportional limit and other physical characteristics determined at room temperature.

In order to convert the load from pounds per square inch gauge of interior tube surface to tensile stress in the wall, the following formula of Clavarino was used:

$$f = P \frac{(13D_1^2 + 4D_2^2)}{10\ (D_1^2 - D_2^2)},$$

in which f = tensile stress in the tube wall,

P = pounds per square inch of interior surface,

D_1 = outside diameter,

D_2 = inside diameter.

This formula serves to include the stresses due to end pressures as well as to make the above indicated conversion.

Clavarino's formula gave the following hoop stress for the two test pressures used:

400 pounds per square inch gauge — 2056 pounds per square inch,
600 pounds per square inch gauge — 3084 pounds per square inch.

Results of Tests.

CHEMICAL ANALYSIS.

A chemical analysis of the boiler tube material disclosed it to have the following composition:

Carbon	0.135 per cent
Sulphur	0.021 " "
Phosphorus	0.020 " "
Manganese	0.520 " "
Silicon	0.130 " "

The microstructure of the tubing showed it to be normal for this composition and to be fully annealed.

TENSILE TESTS.

Tests at room temperature gave the following physical characteristics:

Johnson's limit	31,250 pounds per square inch
Proof stress	25,250 " " " "
Yield point	34,500 " " " "
Ultimate strength	52,600 " " " "
Elongation	34 per cent
Reduction in area	60 " "

RUPTURE TESTS.

A survey of the literature has revealed that whereas considerable research has been conducted in the behavior of carbon and alloy steels under internal pressure at elevated temperatures, the test conditions were in no case such as to allow one to predict the behavior of naval boiler tubing stressed due to internal pressure at temperatures between 1200 and 1800 degrees F. Some investigators consider an accurately determined proportional limit as indicating the limiting stress condition, others choose to ignore the

effect of plastic flow or "creep," believing that a tube would fail primarily through thinning of the tube wall due to oxidation. In all cases the published test temperatures employed did not exceed 1500 degrees F. Since ruptured boiler tube specimens examined under the microscope at the Naval Engineering Experiment Station showed metal temperatures in excess of 1600 degrees F. at the time of the rupture in many cases, it appeared advisable to conduct tests simulating as far as possible the conditions existing in a boiler tube that was steam bound due to any one of a number of causes. The test pressures selected were 400 and 600 pounds gauge paralleling present marine practice. White and Clark [2] preferred to conclude their tests at the point at which the tube section began to bulge or bag. To the writer, however, continuing each run to the state of rupture appeared to more closely approximate service conditions. The tests covered by this paper were run accordingly and the data plotted as shown on Figure 4 from the following table:

Temperature Degrees F.	*Time to Rupture in Hours at Pressures of*	
	400 P.S.I.	*600 P.S.I.*
1200	346.2	134.8
1200	354.8	—
1300	184.3	23.4
1300	—	28.2
1400	32.6	11.2
1400	35.3	—
1400	32.0	—
1500	11.4	3.2
1500	—	3.3
1600	11.8	—
1600	7.6	—
1800	1.9	—
1800	1.5	—

It has been generally accepted that a low carbon steel boiler tube may be operated continuously at a metal temperature not exceeding 900 degrees F. providing water or a steam-water mixture is freely circulated through it. Above this temperature, the effect of

"creep" and oxidation of the tube wall will cause early failure. This figure appears to be verified by the general trend of the curves of Figure 4.

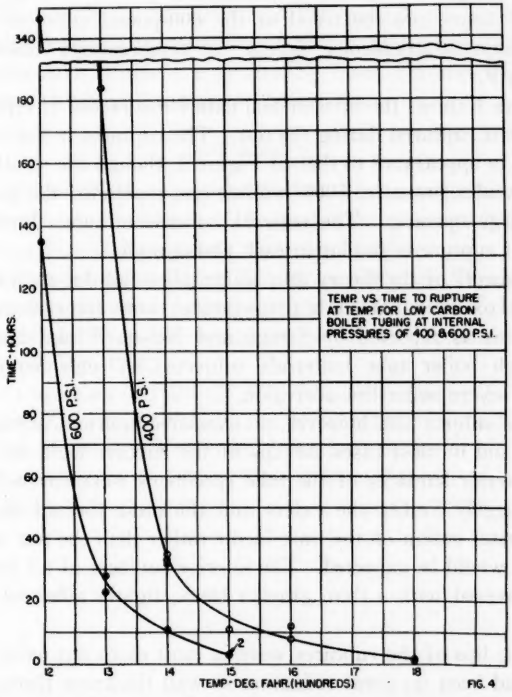


FIG. 4

The importance of maintaining at least partial and continuous circulation in the fireside row of a boiler operating at high rates of combustion with furnace temperatures approaching 3000-3200 degrees F. is amply illustrated. Interrupting the established circulation in a boiler tube may be caused by blockage through foreign objects, but more likely it is due to movement of the boiler platform in a seaway. Should the circulation not be re-established within a short time, rupture of the tube will take place at the hottest portion, which appears to be in the half of the tube nearest the steam drum in the usual express-type boiler.

Increasing the boiler operating pressure from 400 to 600 pounds indicates that the necessity for maintaining circulation, particularly in the generating tubes of a boiler, can hardly be overestimated. At 1500 degrees F. the tube specimens ruptured after an average of 3.25 hours and the trend of the 600-pound curve is towards practically instantaneous failure at temperatures above 1550 degrees F.

Figure 5 shows the interior and exterior surfaces of typical tube specimens ruptured during the test. The ruptures in the tubes are similar in appearance to that of Figure 1, though the small volume of air under pressure, 5000 centimeters, precluded the possibility of a large opening. The network of discontinuous lines at the point of rupture is similar in each photograph.

Exponents of the theory that boiler tubes fail due to heat corrosion or oxidation at high temperatures note internal corrosion conditions as reported by Straub and Nelson [3] and Hanson,[4] in which boiler tube materials subjected to high temperatures exhibit severe water-line corrosion.

In the subject test, however, no excessive internal corrosion was found, and in most cases the lips of the rupture were oxide free. The exterior surfaces of the tube specimens were covered with a scale, largely Fe_3O_4, the extent and thickness thereof depending to a greater extent on the time factor rather than the test temperature, as would be expected. The interior surfaces of all specimens were covered with a thin, grayish black, tightly adherent, Fe_3O_4 scale.

As the lips of the ruptures were in most cases not oxidized and there had been no great reduction in wall thickness through heat corrosion, it must be assumed that the tube failures at the temperatures and pressures employed were due to "creep" or plastic flow of the metal.

Conclusions.

As the result of the tests herein described, it is believed:

(1) That the primary cause of failure of the test specimens at temperatures up to 1800 degrees F. was "creep" or plastic flow, rather than heat corrosion.

(2) That at elevated temperatures, 1200-1800 degrees F., time and a lower temperature appear to cause the most oxidation of the tube specimens; i. e., more heat corrosion took place at 1200 degrees F. for 350 hours than at 1800 degrees F. for 1.9 hours.

(3) That with the utilization of 600 pounds per square inch operating pressures maintenance of proper and adequate circulation, particularly within the generating tubes, becomes of utmost importance if tube failures are to be avoided.

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(3) "Corrosion in Partially Dry Steam-Generating Tubes," by F. G. Straub and E. E. Nelson, and presented before the American Society of Mechanical Engineers, February, 1939.

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THE COLLAPSE OF HARD AND SOFT COPPER TUBES UNDER EXTERNAL PRESSURE.

By MAURICE G. STEELE, Member.*

Tubes which are properly designed to resist substantial internal pressures are almost invariably capable of withstanding any external pressures to which they may be subjected. However, the designing engineer must not neglect the occasional. At times it is necessary to determine the external pressure at which a tube of given composition, hardness, and physical dimensions will fail in collapse, and here it is that the designer is confronted with a paucity of dependable information. The author remedies this deficiency for thin copper tubes.

In 1858 Fairburn developed from his experiments formulae for the strength of steel boiler flues. Lloyd's Register, the British Board of Trade and Nystrom also developed formulae, but they possessed the common defect that they make the collapsing pressure decrease definitely with increase of length and vice versa. Subsequent tests by Professor R. T. Stewart showed that all the old formulae were not applicable to the wide range of conditions found in modern practice. Among other things, he ascertained that the length of tube between transverse joints tending to hold it in circular form, has no practical influence upon the collapsing pressure if the length is not less than six diameters of the tube.

Improved formulae for tube collapse were developed by Lamé and Love, from which S. E. Slocum in 1909 deduced some rational formulae for thick and thin tubes of both steel and brass. Correction factors for average ellipticity and variation in thickness were applied, resulting in what appear to be fairly dependable formulae. Carman, in University of Illinois Bulletin No. 17-1906, published an empirical formula for thin seamless brass tubes

$$P = 25{,}150{,}000\ (t/D)^3.$$

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This apparently applied a combined factor of 0.78 for average ellipticity and variation in wall. No correlation of this formula with the physical properties of the tube material has as yet been located by the writer and without this the formula cannot be intelligently used. It is obvious that tubes differing in chemical composition and in hardness will collapse at pressures that vary considerably. Test data contained in this paper prove this point.

For instance, checking the above formula against actual collapse data on duplicate specimens of 1-inch O.D. hard copper tube, Types K, L, and M, we get values for the factor of 18,350,000, 23,200,000 and 30,250,000, respectively. These variations would make it appear quite obviously that this formula is not applicable to copper tubing. For dimensions of these various types of standard tube see tables under Figure A.

The writer feels that a more dependable and practical method of obtaining accurate design data for tubing which is to be subjected to external pressure, is to make practical collapse tests on tubes of various diameters and gauges in different alloys, with an accompanying correlation of physical properties of the tube material in question. This will permit intelligent selection of tube sizes for successful resistance to known external pressures.

It might be well, in passing, to discuss some of the more common causes of tube collapse. These might be enumerated as:

1. Excessive external pressure from any source, such as failure of pressure reducing valve.
2. Shock loading, such as that produced by water hammer.
3. Existence of a sub-normal pressure inside the tube due to restriction in pump lines, improper closing of a valve, sudden condensation of steam or vapor, etc., etc.
4. Inadequate design.

A practical example of such failure occurred in a marine installation, which developed difficulty with condensate draining properly from the bottom of the main condenser. A 5-inch lagged copper line connected the condenser drain to the pumps. Investigation showed that this tube had collapsed under external atmospheric pressure, due to a stoppage in the line which caused the pumps to draw through a greatly restricted orifice. It was also determined

TABLE OF DIMENSIONS AND WEIGHTS OF STANDARD COPPER WATER TUBE.

DIAMETER OF TUBE IN INCHES		TYPE K		TYPE L		TYPE M	
Nominal	Actual O.D.	Wall Thickness Inches	Weight lbs. per ft.	Wall Thickness Inches	Weight lbs. per ft.	Wall Thickness Inches	Weight lbs. Per ft.
3/8	.500	.049	.269	.035	.198	.025	.144
1/2	.625	.049	.344	.040	.285	.028	.203
5/8	.750	.049	.418	.042	.362	-	-
3/4	.875	.065	.641	.045	.455	.032	.328
1	1.125	.065	.839	.050	.655	.035	.464
1-1/4	1.375	.065	1.040	.055	.884	.042	.661
1-1/2	1.625	.072	1.360	.060	1.140	.049	.940
2	2.125	.083	2.060	.070	1.750	.058	1.460
2-1/2	2.625	.095	2.920	.080	2.480	.065	2.030
3	3.125	.109	4.000	.090	3.330	.072	2.680
3-1/2	3.625	.120	5.120	.100	4.290	.083	3.580
4	4.125	.134	6.510	.110	5.380	.095	4.660
5	5.125	.160	9.670	.125	7.610	.109	6.660
6	6.125	.192	13.870	.140	10.200	.122	8.910
8	8.125	.271	25.900	.200	19.290	.170	16.460
10	10.125	.338	40.260	.250	30.040	.212	25.570
12	12.125	.405	57.760	.280	40.360	.254	36.690

FIGURE A

that the tube wall had not been properly designed and was inadequate for the service.

Another instance of failure that is quite probably attributable to water hammer is that of a .067-inch wall × 1¼-inch O.D. copper U tube which was removed from a low-pressure steam-hot water heater of conventional design. This tube, which is shown in the accompanying illustration (Figure B), contained low-pressure steam and was surrounded by water pressure of around 60 pounds per square inch.

It will be seen that the arc of the U has been collapsed flat in one plane, while the two leg portions are flattened in a plane at 90 degrees to it.

There is an interesting feature of tube collapse under external pressure which, while quite obvious, might well escape attention. This is that a collapsing tube does not fail because the fibres of the tube wall have reached the ultimate tensile or ultimate compressive stress of the material at the point of initial failure. The tube wall does not rupture during collapse as it does in the case of failure due to excessive internal pressure.

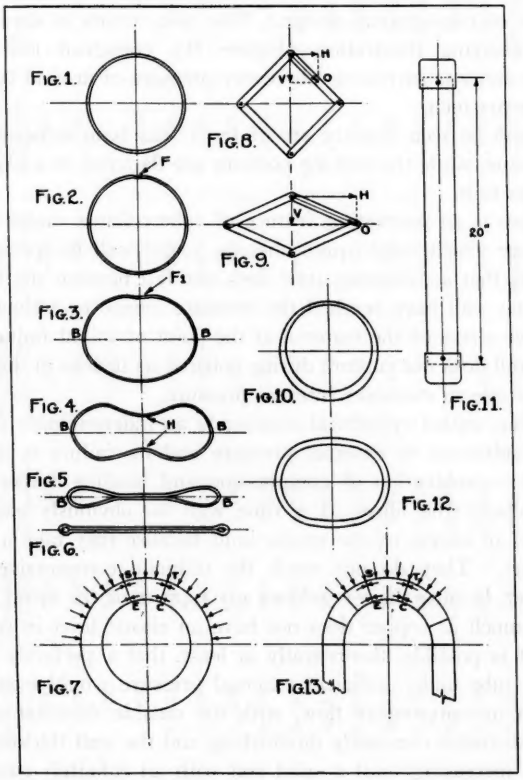
A thin walled cylindrical member is an indeterminate structure when subjected to external pressure and its failure is due to a complex combination of compression and bending forces. During collapse the fibres of a tube wall do obviously experience stresses in excess of the elastic limit because they take a permanent set. They do not reach the ultimate compressive stress, however, because there is seldom any rupture of the metal.

Inasmuch as copper does not have an elastic limit in compression, it is possible, theoretically at least, that a perfectly formed copper tube under sufficient external pressure would continue to deform in compressive flow, with the outside diameter and the inside diameter constantly diminishing and the wall thickness constantly increasing until a solid rod with an infinitely small core (void at the longitudinal axis) resulted.

Mechanism of Collapse.

When a perfectly formed round tubular structure is subjected to external pressure, this pressure is radial to the outside surface at all points and is uniformly applied. This is indicated in Figure 7. The tube section is then in perfect equilibrium.

If we consider a sector of this tube wall S E C T which is, of course, also in equilibrium, the radial pressure produces components in the wall fibres that are entirely compressive in nature as



is the case in the keystone of a masonry arch as shown in Figure 13. If the tube were perfectly symmetrical and of uniform manufacture, failure would not result until the wall failed due to compressive distortion.

No tube is perfectly formed, however, and all evidence points to the fact that collapse failure starts at the weakest point in the tube section and centers lengthwise about the longitudinal location of the weak point.

The focal point of the starting of collapse is undoubtedly the result of one of four causes as follows:

1. Eccentricity or lack of wall uniformity (see Figure 10).
2. Ellipticity or lack of roundness (see Figure 12).
3. Manufacturing defects in the tube wall such as dirt, slivers, cold shuts, inclusions, etc.
4. Damaged tube wall.
5. Combinations of the foregoing.

Any of these factors obviously lower the collapsing pressure of the tube.

The actual mechanism of failure might be compared to the action of a toggle joint as shown. Figure 8 shows a toggle made up of four equal links forming a perfect square. Obviously if equal pressure is exerted at all four pivotal points of this linkage and directed toward the center thereof, the system will be in equilibrium and no motion will result. This situation compares with a perfect tube under pressure as shown in Figure 1.

As the pressure is increased, however, on a tube which is not perfect, localized deflection eventually takes place at a point of weakness which is due to a defect, to eccentricity, or ellipticity. This bending may be similar to the deflection of a beam of non-uniform section under uniform loading.

Once this deflection starts a palpable flat area is established which eliminates the radial application of the external pressure and substitutes a concentration of pressure over this small area in *one* and the *same* direction. This slight deflection and orientation of force direction cause the toggle to move slightly out of the equilibrium of Figure 8 and the horizontal component of force H increases, producing bending at points B B. (See Figure 3.)

Once this motion starts it accelerates due to the rapid increase of component H, which becomes infinitely great when the angle between the links is zero, and to the accompanying increase in the

flattened area and the total pressure exerted on it. An intermediate position of the toggle is shown in Figure 9 which has its tube counterpart in Figure 3 or Figure 4.

Figures 1 to 6, inclusive, show roughly the different stages in the collapse of a relatively thin tube. In Figures 2 and 3 the starting point of failure is indicated by F and F. It will be noted that as collapse progresses it is accompanied by lateral spreading of the tube to produce an elliptical section and the bending at points B B becomes more and more articulate.

When the typical peanut shape of Figure 4 is reached, and probably before this stage, some of the inner fibres of the tube wall have reversed from compression to tension. Tension stresses, however, have nothing to do with the initial failure.

The logic of the toggle analogy is attested by the fact that after bending starts the tubes can be completely collapsed with less and less pressure as the minor axis of the ellipse decreases and the flattened area increases. In other words, once collapse has started, it requires relatively little pressure to carry collapse to completion and, within reasonable limits of size and gauge, the pressure required to complete collapse of any tube varies little.

Apparatus.

The apparatus used in the collapse tests, which is illustrated in Figure 14, is extremely simple and has no outstanding points of novelty.

The compression chamber was made from a piece of extra heavy steel pipe to which was welded suitable supporting angle legs.

A disc was welded into one end with a tapping for the inlet pipe connection. A very heavy steel flange, equipped with eight bolts and recessed gasket grooves was welded to the other end and a solid companion flange provided. An air vent cock was provided at the top of the cylinder which was inclined slightly to permit the purging of air from the cylinder.

The other features are quite familiar, including water supply inlet valve, calibrated pressure gauge and hydraulic hand pump.

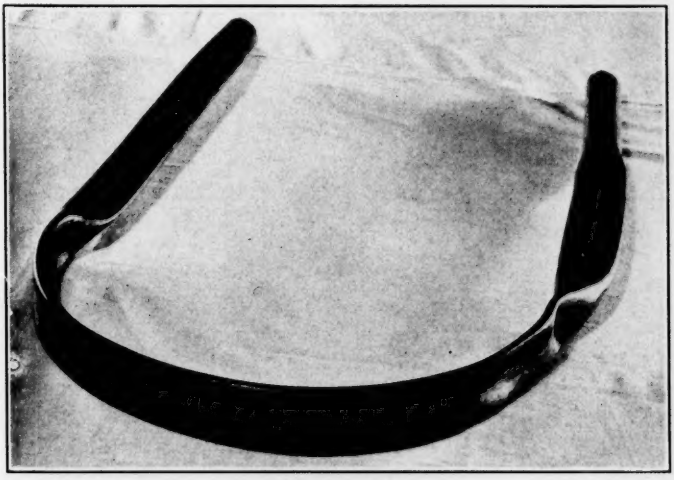


FIGURE B.

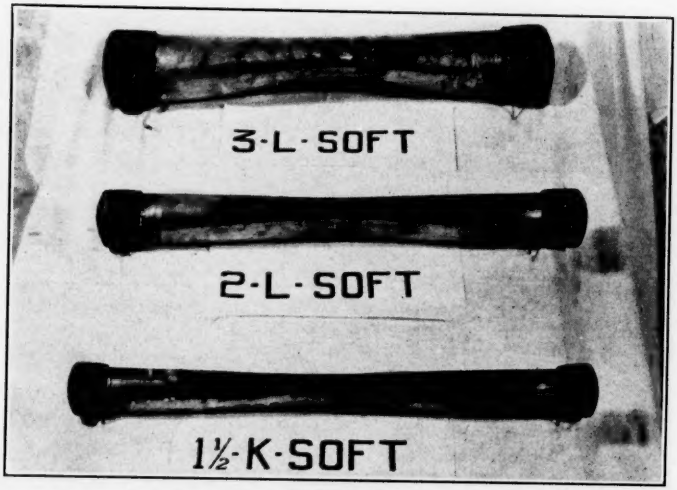
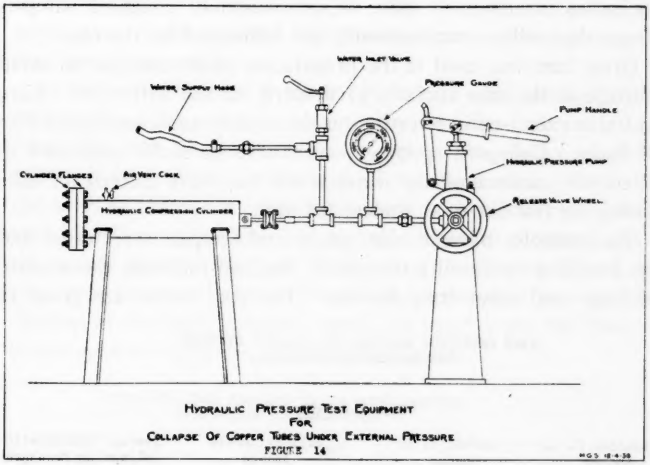


FIGURE C.

FIGURE D.



HYDRAULIC PRESSURE TEST EQUIPMENT
FOR
COLLAPSE OF COPPER TUBES UNDER EXTERNAL PRESSURE
FIGURE 14

TESTS.

It was decided to test a range of diameters and wall thicknesses of standard copper water tubing in both the annealed and commercially hard condition. Selection was made of Types K, L, and M in ½ inch, 1 inch, 1½ inch, 2 inch and 3 inch O.D. For a complete table of sizes and weights of standard copper water tubing refer to Figure A.

Type K tubing is generally used for underground services, general plumbing purposes, and severe water conditions; also for gas, steam, and oil lines and other industrial uses. Furnished in hard or soft temper.

Type L tubing is used for general plumbing purposes; it is suitable for normal water conditions; also for gas, steam, and oil lines and other industrial uses. Furnished in hard or soft temper.

Type M tubing is used for general plumbing purposes with solder fittings only. It is also suitable for normal water conditions; also for gas, steam and oil lines and other industrial uses. Usually furnished in hard temper only.

Sweated cap fittings were employed as closure members. To avoid any possibility of a supporting influence on the part of the end caps all test specimens were made 20 inches long with about

18 inches unsupported span. Examination of collapsed samples shows that collapse was probably not influenced by the caps.

Great care was used in the preparation of the samples to avoid damage to the tube surface, particularly on the soft tubes. Care was also exercised in sweating on the caps to avoid any possibility of leaks. Collapsed specimens were also carefully examined to detect the presence of any water which may have entered the tube during the test due to an undetected leak.

Two samples of each size, gauge and temper were tested and the excellent uniformity of results obtained indicates the absence of leaks and other irregularities. The test results are given in

TEST PRESSURES REQUIRED TO COLLAPSE STANDARD COMMERCIAL COPPER TUBING.

Nominal O. D. Inches	Actual O. D. Inches	Wall Thickness Inches	Average Hydrostatic Collapsing Pressure Lbs. per sq. in.
Type K - Soft			
1/2	5/8	.049	895
1	1-1/8	.065	435
1-1/2	1-5/8	.072	371
2	2-1/8	.083	250
3	3-1/8	.109	250
Type L - Soft			
1/2	5/8	.040	575
1	1-1/8	.050	275
1-1/2	1-5/8	.060	240
2	2-1/8	.070	238
3	3-1/8	.090	175
Type M - Soft			
1/2	5/8	.028	283
1	1-1/8	.035	143
1-1/2	1-5/8	.049	145
2	2-1/8	.058	145
3	3-1/8	.072	130

FIGURE 15

tabular form in Figures 15 and 16. The observed collapsing pressures given in the extreme right-hand column are the average of two tests in each case.

In the case of the soft tubes (Figure 15) the average difference in observed collapse pressure readings for each set of two tubes was 12.5 pounds per square inch. The maximum difference was 30 pounds. In the case of the hard tubes (Figure 16) the average difference was 40.7 pounds with a maximum difference of 100 pounds. This 100 pounds difference occurred only in the case of three of the Type K tubes and the ½-inch Type L and was doubtless due to the difficulty of obtaining a precise gauge reading at the high pressures used. In many cases the observed pressures were identical for two similar tubes.

TEST PRESSURES REQUIRED TO COLLAPSE STANDARD COMMERCIAL COPPER TUBING.

Nominal O. D. Inches	Actual O.D. Inches	Wall Thickness Inches	Average Hydrostatic Collapsing Pressure Lbs. per sq. in.
	Type K - Hard		
1/2	5/8	.049	Undetermined
1	1-1/8	.065	5050
1-1/2	1-5/8	.072	3050
2	2-1/8	.083	2050
3	3-1/8	.109	1900
	Type L - Hard		
1/2	5/8	.040	5550
1	1-1/8	.050	2900
1-1/2	1-5/8	.060	1950
2	2-1/8	.070	1563
3	3-1/8	.090	1300
	Type M - Hard		
1/2	5/8	.028	3125
1	1-1/8	.035	1300
1-1/2	1-5/8	.049	1400
2	2-1/8	.058	1015
3	3-1/8	.072	738

FIGURE 16

The test procedure is simple. Tube sample is placed in compression cylinder which is then tightly sealed by the flanged head. The water inlet valve is next opened admitting water to cylinder, air vent cock being opened to permit air in cylinder to escape. When the cylinder is filled with water the air vent cock and the water inlet valve is closed. The release valve on the pump is closed and pressure is slowly produced on the system by the operation of the pump handle.

Care is taken at all times to use small, steady strokes on the pump to avoid a pulsating pressure which might cause premature failure. The hand of the pressure gauge is watched carefully by two or three observers. At the instant of failure of the tube the pointer drops suddenly. This permits of accurate observation of the collapse pressure.

It will be noted from the accompanying photographs of collapsed samples (see Figures C and D) that some of the smaller tubes have been completely flattened while the larger ones are only partially collapsed. This is doubtless due to the fact that a small amount of air was trapped in the cylinder at the start of each test. This air acted as a recuperator, making the hydraulic bath elastic. The expansion of this air at the beginning of tube failure was sufficient to extend the collapsing action even after operation of the pump had ceased.

The results of the tests (see Figures 15 and 16) were plotted with pressure in pounds per square inch as the vertical coordinates, and wall thicknesses as horizontal coordinates. The resulting curves (see Figures 17 and 18) for the various tube diameters in both soft and hard copper are quite consistent and satisfactory. They are slightly more regular for the hard tubes than for the soft, which is to be expected for reasons already cited.

Vertical cross sections of the above curves were made and a new series developed with pressure as the vertical coordinates and nominal O.D. as horizontal coordinates. These sections were taken for nine different values for wall thickness from 0.030 inch to 0.110 inch at intervals of 0.010 inch.

These latter curves (see Figures 19 and 20) constitute reliable design data which is simple in form and convenient to use.

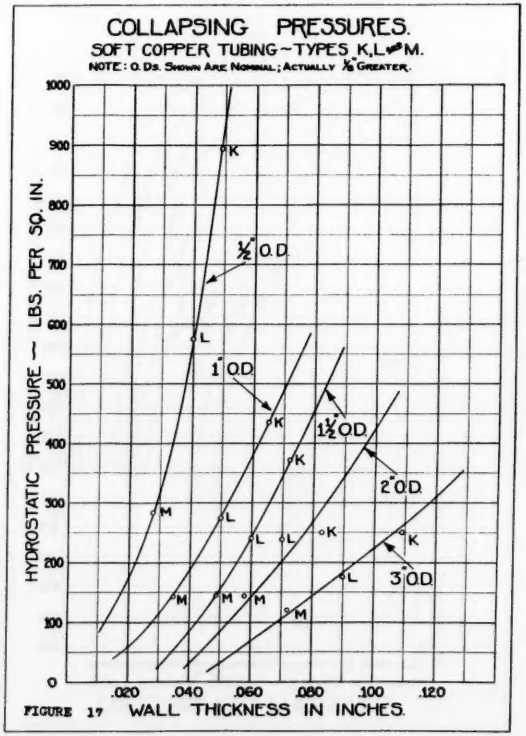


FIGURE 17

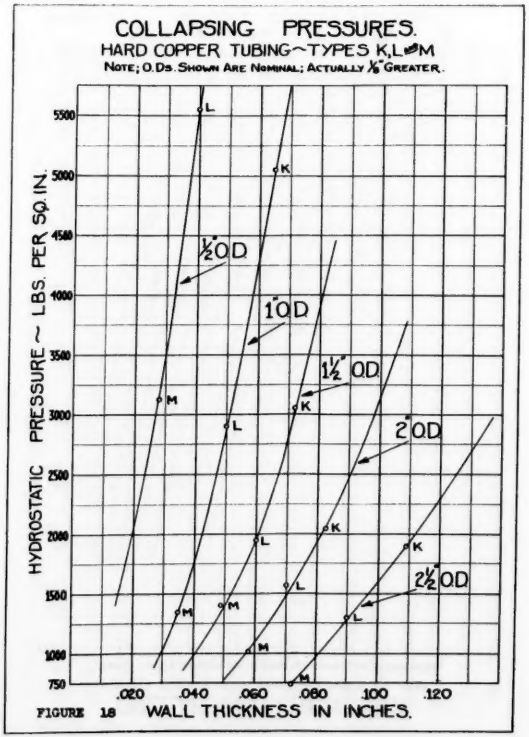


FIGURE 18

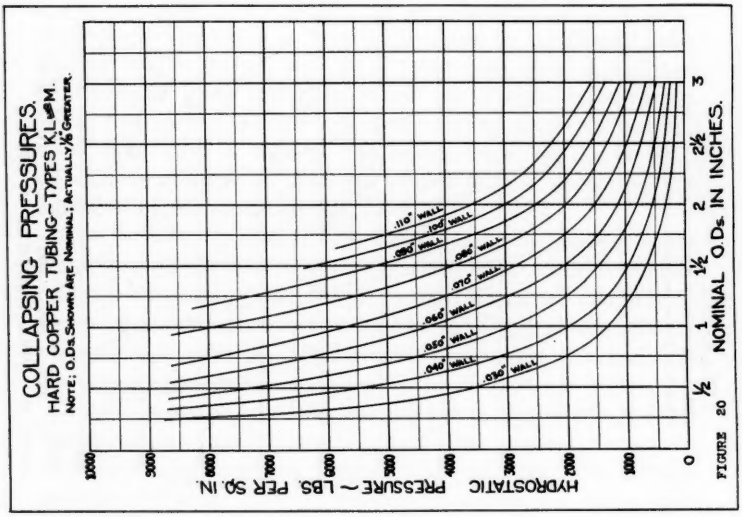


FIGURE 20

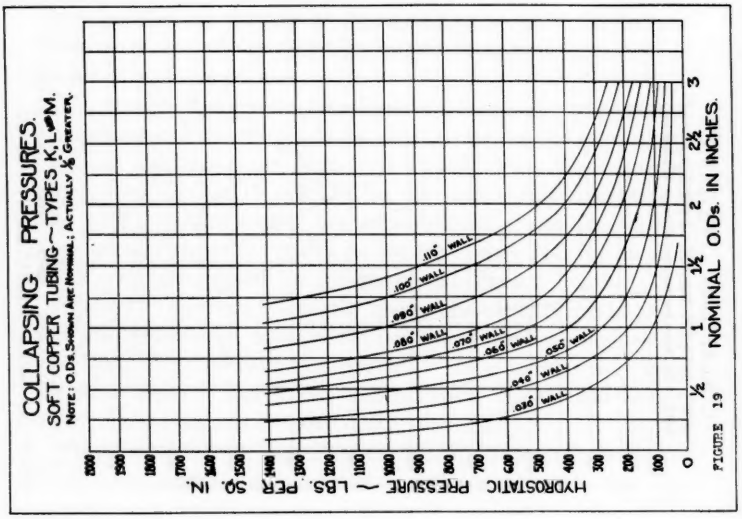


FIGURE 19

In making use of these curves a suitable safety factor should be allowed to cover the contingency of shock load, water hammer, etc. A factor of safety of 3 is often used. This is a case, however, where sound engineering judgment must be employed and a proper factor of safety used, depending upon intended conditions of use and due consideration of the greatest pressure that the tube in question might be subjected to.

Nominal O.D.'s have been used for the Types K, L, and M tubes in plotting test results. It should be carefully noted that in each case the actual O.D. is 1/8 inch greater than the nominal. This should be borne in mind when using these curves. For a tube that is actually one inch O.D. for instance, reference should be made from the 7/8 inch diameter vertical coordinate.

It is felt that the values for hard tubes are more useful than those for soft tubes, as hard tubes are more often used where collapse is a possibility.

PHYSICAL VALUES

Soft Copper Tube
(Annealed at 1160°F.)

Diam.	Type	Ave. Grain	Tensile	Elongation %	Elongation Inches
1/2	K L M	.075	32,300	45	8
1	K L M	.050	32,500	46.8	8
1-1/2	K L M	.042 .042 .055	33,900 32,200 33,900	47.5 40.0	8 8
2	K L M	- Values not taken *		-	
3	K L M	- Values not taken *		-	

* Approximately same as 1-1/2" diameter.

FIGURE 21

Soft tubes are not much used in mechanical applications except where bending is a requisite. They are usually used for conducting water, gas, or other fluids and the external pressures encountered are seldom great enough to cause collapse.

It is a self-evident fact that, inasmuch as hard and soft tubes of the same O.D. and gauge collapse at widely separated pressures, that any collapse values to be useful must be correlated with definite physical data for the tubes actually tested.

Determinations of Rockwell Hardness, tensile strength, and elongation were made on the hard tube samples used in these tests. These values have been tabulated, together with data regarding the number of draws, through the drawing die, after the last anneal and the total subsequent cold reduction. These values, which are given in Figures 21 and 22, will enable the designing engineer to specify rather closely the physical properties of a tube he has selected from the curves. By so doing he will be certain of the amount of resistance of this particular tube to external pressure.

PHYSICAL VALUES

HARD COPPER TUBE

Nom. Dia.	Type	No. of Draws	% Total Reduction	Rockwell B Hardness 1/16 ball, 100 kg load	Tensile Strength	Elongation %	Elongation Inches
1/2	K	1	20	44-45			
	L	1	19 1/2	39-40			
	M	2	53	52-53	57,600		
1	K	1	19	40-45			
	L	1	20	43-45	41,500		
	M	2	52	55	55,000		
1-1/2	K	1	19.3	48	45,100		
	L	1	19	39-41	41,800		
	M	2	50	50-55			
2	K	1	18.4	42-43			
	L	1	19	45-46			
	M	2	41	50-55			
3	K	1	20	39	41,400		
	L	1	20	40	42,600		
	M	1	31	45-50			

APPROXIMATE MILL VALUES

HARD COPPER TUBE

K&L	1	App. 20	39-46	40,000-45,000	10%	4"
2½ & less M	2	40-50	50-55	App. 55,000	3 to 5%	2"
3 & over M	1	30	45-50	App. 50,000		

FIGURE 22

Types K and L hard tubes were given one draw with an average reduction of 20 per cent, an average Rockwell B Hardness (1/16 ball; 100 kilograms load) of 30 to 46, an average tensile strength of 40,000 to 45,000 pounds per square inch, and an average elongation of 10 per cent in 4 inches.

Type M hard tubes 2½ inches diameter and less were given two draws with an average total reduction of 40 per cent to 50 per cent, an average Rockwell B Hardness of 50 to 55, an average tensile strength of 55,000 pounds per square inch, and an average elongation of 3 per cent to 5 per cent in 2 inches.

The Type M hard tubes 3 inches diameter (and this applies to O.D.'s over 3 inches) were given one draw with an average reduction of 30 per cent, an average Rockwell B Hardness of 40 to 50, an average tensile strength of 50,000 pounds per square inch, and an average elongation of 3 per cent to 5 per cent in 2 inches.

On the soft tube samples, determinations were made of grain size, tensile strength and elongation, which have been tabulated. These samples were annealed at a temperature of 1160 degrees F.

The average grain size was .040 to .050, the average tensile strength 33,000 pounds per square inch and the average elongation in 8 inches was 45 per cent.

Conclusion.

Similar investigations on other alloys are contemplated as well as tests on wider ranges of sizes and tempers. Contemplated also is a study of work previously done on this subject by other investigators and formulae developed by them as a result. There is the possibility of developing a practical formula or formulae for the collapse of copper and copper base alloy tubes under external pressure, but this will require a great deal of mathematical investigation, the analysis of the results of actual collapse tests, and a reconciliation of the two.

Grateful acknowledgement is hereby made to Mr. Ralph E. Vining, Supervisor of Methods, and Mr. Joseph Graber, Laboratory Assistant, of the Baltimore Division, Revere Copper & Brass, Inc., for their painstaking labors and fine cooperation in making the collapse tests which have served as a basis for this paper.

A SHORT HISTORY OF THE NAVAL USE OF FUEL OIL.

PART VII.

By Lieutenant Commander James E. Hamilton, U. S. Navy, Member.*

The author's history is concluded in this part. Under the subhead "Supply and Distribution" he covers first the events between the removal of the petroleum from its source and its acquisition by the Navy; then the circumstances which result in its bunkering on board Naval vessels. The importance of fuel oil storage facilities and of tankers is stressed. These, of course, can only be initiated by Congress. The author reveals an adequate understanding of the subject by responsible Naval officers. But he suggests the handicaps imposed by congressional inaction during the post-war period when high lights were reflected from the Navy's attempts to circumvent the restrictions thus imposed.

Supply and Distribution.

During the fiscal year 1919, which embraced the last few months of the war and the first large deliveries of the oil-burning destroyers and Eagle boats of the war program, the Navy used a total of 10,500,000 barrels of fuel oil. Based on approximate conversion figures, this represented but 37 per cent of the fuel used during that year. Coal still accounted for 63 per cent of the Navy's fuel need. Had all vessels at that time been oil burners, the demand would have been nearer 30,000,000 barrels.

The supply of fuel oil throughout the war was handled by placing "Navy Orders" with the various suppliers on the basis of their relative capacities to produce it. This purchase by allocation was authorized by Congress as necessary to the prosecution of the war. It is a much simpler method than the conventional way

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of obtaining supplies through competitive bidding. There was one flaw in the method. In order that supplies might be obtained without delay and as needed, the navy order provided that, in the event agreement could not be reached as to price, the Navy could take the supplies by paying a price which it considered to be reasonable. The supplier could then prosecute a claim to obtain any difference between the price paid and what he could prove to be just.

In the case of many fuel oil orders, particularly on the West Coast, final settlement was still pending after the war and adjudication was slow because the suppliers demanded a much higher price than the government would accept as reasonable. This circumstance led in 1920 to a very unsatisfactory condition on the West Coast, where the oil companies, believing that they had been unfairly treated, were very unsympathetic toward the Navy and its needs. This condition was aggravated by two things.

WEST COAST FUEL OIL SUPPLY.

In 1919 the Secretary of the Navy had divided the Fleet, establishing for the first time one complete fleet in each ocean. All types of vessels were divided about equally between the two coasts, with the result that more naval vessels had become dependent on a West Coast source of fuel than ever before. As new destroyers were completed and joined the fleets, the demand became heavier and heavier through 1919 and 1920.

The Shipping Board's construction program, paralleled the Navy's destroyers very closely. Practically all of these ships were oil burning. The extremely heavy demand for shipping immediately after the war kept these new ships operating and their fuel requirements were enough in themselves to give the oil companies all the business that they could handle. There was practically no commercial incentive to cater to the Navy. Patriotism had overcome any differences while the war was actually in progress, but at its conclusion, patriotism did not necessarily embrace support of a large fleet and its large-scale operation. Very probably the oil supplier could see no injury to the national defence if the fleet should be denied mobility in peacetime because of lack of fuel. He had to worry about regaining his markets which some of his

foreign (recently allied) competitors had not hesitated to take over during the war.

As a result, reduced operations became necessary before the economy wave which followed made them mandatory. A great many officers will remember how the destroyers in San Diego frequently had to pool what little oil was available in the tanks of many of them to permit one to carry out some operation. At one stage conditions were such that an Admiral on the West Coast demanded that a certain refinery deliver fuel oil to his ships and threatened that if this were not done, he would seize the refinery with military force. The refinery manager answered that his orders were to refuse to deliver oil to the Navy and that if men were landed to take over the plant, he would remove all of his own force. Since both the manager and the admiral doubted the ability of the bluejackets to operate the refinery satisfactorily, these threats and counterthreats led to a stalemate, except that the ships did not get the fuel that they needed.

Continued negotiations, coupled with a gradually reduced naval requirement due to the effects of generally applied economy, and the increase of the supply due to increased production of petroleum, eventually led to agreements which reestablished the Navy's West Coast fuel oil supply on the regular peacetime basis of competitive bidding. As the Los Angeles basin fields were discovered and opened up and as a return to sub-normalcy in commercial shipping made the Navy's business more attractive to the oil companies, the matter of *supply* of fuel oil on the West Coast ceased to present any problems except those connected with quality. The possible effect of this condition has been considered heretofore.

EAST COAST FUEL OIL SUPPLY.

While the West Coast was presenting its fuel oil supply problems, the Navy was not having an easy time with the question on the Atlantic seaboard. The demand on the East Coast for petroleum products other than fuel oil was naturally much greater than on the Pacific. Since the normal domestic supply of petroleum available to East Coast markets, principally that from Texas and the Mid-Continent fields, was generally high grade and susceptible to processing for relatively small quantities of bunker fuel oil, the

trade had turned to the highly prolific Mexican fields. This Mexican production was low-grade petroleum, but satisfactory for use as bunker fuel oil for most commercial purposes.

The Mexican supply began to show signs of definite and permanent decline just as the increased demands for commercial fuel oil which followed the war began to be felt. The laws of supply and demand took charge and the price of fuel oil soared unbelievably. The Navy was just a customer like anyone else. On a contract which expired with fiscal year 1920 on June 30, 1920, the Navy was obtaining fuel oil at Port Arthur, Texas, for 83 cents per barrel. On that date the price on the market at Port Arthur exceeded three dollars per barrel.

When the Navy Department opened bids in March, 1920, for its East Coast supply of fuel oil for the next fiscal year, only two bids had been received. One of these offered fuel oil, of the grade required, at New York for $4.20 per barrel as compared to the then current Navy contract price of $1.49. The other offered delivery at Baltimore for $3.65 as against the current contract price of $1.54. The total fuel oil offered by the two bids was only 719,000 barrels for the first six months of the fiscal year whereas the Navy had asked for two and a half million barrels. Both of these bids were considered unsatisfactory and were rejected. Special letters were addressed to each of the large suppliers of fuel oil describing the needs of the Navy and requesting new offers.

In its earlier requests the Navy had specified "Navy Fuel Oil" which was identical with the best grade of commercial fuel oil, Bunker A, except for a minimum sulphur requirement. On the second advertisement, the requirement was reduced to a straight Bunker A, which through the elimination of the sulphur limitation should have broadened the supply.

Although five bids were received for the second opening in April, 1920, only one of them offered fuel oil which met the specifications advertised. The one quotation on Bunker A fuel oil was $3.75 per barrel delivered at Fall River, Massachusetts. This bid was much too high in the opinion of the Navy Department, so the bids were again rejected and direct negotiations resorted to. On its side of the negotiations the Navy held the threat

of commandeering. On the side of the oil companies was the high market price and the general shortage of tankers which made the importation of Mexican crude oil very uncertain. Agreement was finally reached which led to contracts with four companies for deliveries of sufficient quantities of satisfactory fuel oil at Port Arthur, Texas, to take care of the Navy's needs for the first half of the fiscal year, that is, from July 1 to December 31, 1920. The fixed price in the contracts was $2.85 per barrel and the Navy guaranteed transportation for the Mexican crude oil needed for making the fuel oil.

These arrangements could not be extended beyond the end of the calendar year and it appeared, in the Spring of 1920, that no early improvement in the general fuel oil situation could be expected. It was necessary to look farther into the future, particularly since the first joint fleet maneuver planned for January, 1921, would require considerable fuel. At the time of the second bid opening in April, the firm of Cochrane, Harper and Company of Boston, which had made the only offering of Bunker A fuel oil, had submitted an alternate bid. By the terms of this bid the company offered to supply the Navy with 3,000,000 barrels of Bunker A at Fall River, Massachusetts, at a price of $3.246 per barrel on the condition that the government would make advance payments totalling $3,500,000 for the construction of a refinery.

The advance payment appeared to be a serious obstacle and was at best undesirable. However, it could still be done under the authority of war legislation and the problem of fuel oil supply beyond the end of the year looked like a bad one. As well as the futures of fuel oil could be predicted the Fall River price appeared to be better than could be expected by any other method of purchase.

The apparent urgency of the situation induced the Assistant Secretary of the Navy to accept Cochrane, Harper's alternate bid. The bidder formed the New England Oil Corporation with which the Navy Department entered into a contract. This contract provided, on the Navy's part, for the advance payment to the contractor of $3,500,000 and a guarantee of transportation of 5,000,000 barrels of crude oil from Mexico to Fall River. This latter guarantee was effected through arrangement with the

Shipping Board which had a number of war-built tankers available.

The New England Oil Corporation's contractual obligation was to furnish 3 million barrels of Bunker A fuel oil at a price of $3.246 per barrel and to provide fuel oil storage facilities for the Navy's use at New York and Philadelphia. There were several other provisions of the contract but the ones mentioned are those principally appertaining to the fuel oil supply.

The advance payment was secured by a bond which was secured by a mortgage on all of the land, buildings, and equipment of the refinery. This money was to be returned to the government by reducing the actual cash payment for fuel oil as delivered to $2.08 per barrel. That is: the indebtedness of the contractor to the government would not be entirely cleared until the final delivery of fuel oil.

The contract was signed on May 4, 1920, and delivery of crude oil to the refinery by the Shipping Board as guaranteed by the Navy, and delivery of fuel oil to the Navy f.o.b. the refinery at Fall River were required to start six months later, or on November 4th. This delivery date would have provided 250,000 barrels a month beginning somewhat in advance of the expiration of the contracts which had been executed as a stopgap.

Both parties fell down on deliveries. Except for small driblets; the Shipping Board did not begin deliveries of crude oil until January, 1921, and fuel oil in quantities was not delivered at the refinery until April, 1921. This delay would have been quite serious had conditions in the fuel oil market not improved greatly since the Spring of 1920. As events turned out the failure to deliver on time proved to be nothing more than an embarrassment, and that because of the existence of the contract.

When it became apparent that deliveries would not begin on schedule, the Navy Department again had to advertise for fuel oil. As a result, bids were received and contracts entered into with two of the large old suppliers for 2,900,000 barrels of fuel oil at an average price of $2.46 per barrel. This price was a reduction of almost 15 per cent from the contract price in existence from July to December and was indicative of what had happened to the fuel oil market. It was now apparent that the price which

the Navy was required to pay on the New England contract was excessive and that the forecasting of a few months before had been erroneous.

The Navy had contracts which insured a satisfactory supply of fuel oil for the last half of the fiscal year 1921 at a reasonable price but it also had on its hands a contract involving about the same quantity of oil at a price almost one third greater. Since the contractor had fallen down on his deliveries on the latter contract it is possible that the government might have called him in default and cancelled the contract. The objection to this, and it was a mammoth one, was that the Navy had already paid $3,500,000 for which it had received no return. It is true that this amount was secured by a refinery which had probably been worth that figure at the inflated prices which existed when it was contracted for. It is doubtful if its 1921 replacement value would have been $3,500,000. Even had the refinery been acceptable to the Navy in liquidation of the contractor's obligation, such acceptance would have presented difficulties. The Navy had tried to get congressional authorization to refine oil and had failed. Had it suddenly turned up with a refinery, there might easily have been some unpleasant repercussions.

Even if Congress had accepted the situation, the refinery would have proved to be a white elephant to the Navy. From time to time construction of a Navy refinery for the production of fuel oil had been advocated by individuals in the Navy. However, none of them had contemplated a refinery so situated that both the raw crude oil and the finished fuel oil would have presented a water transportation problem. The Fall River refinery did not fall into any naval picture and the Navy was very anxious to get out of its contract with the New England Oil Corporation without loss and without a refinery.

The only way which could be found for clearing up the contractor's indebtedness was to carry out the major provisions of the contract. Through negotiation practically every requirement of the contract except the supply of 3 million barrels of fuel oil was cancelled and as a result the Government saved a considerable sum. When deliveries of fuel oil from Fall River in April, 1921, became sufficient in themselves to provide for the Navy's needs,

no further deliveries were taken on the other contracts. This, although it meant paying a definite premium for fuel oil, meant also that the New England contract would be cleared up as soon as possible and that was very earnestly desired.

As deliveries were made, the collateral held by the Navy against the contractor's indebtedness was gradually reduced. In March, 1922, the Navy received its last delivery of fuel oil on this contract and at that time fuel oil supply can be considered as having returned to normal from the war and post-war conditions.

This case of the New England Oil Corporation contract has been gone into in great detail because it exemplifies so well the sort of thing which might happen at any time, peace or war, in connection with fuel oil supply. Adequate facilities and stock of reserve fuel oil in readily usable form and location, would permit the Navy to bridge over any unforeseen lapse in the normal supply. These facilities and reserves have frequently been requested by the Navy and just as often have been denied by the Congress.

The best solution which could be worked out in the Spring of 1920 was the one adopted, and yet it failed of its purpose. Had basic conditions not changed it is easily possible that the fleet might have been immobilized for a time. Since the fleet is of real value only because it is instantly available for any service, it is apparent that in 1920 the Navy's fuel oil supply arrangements were highly unsatisfactory. Very little has been done since that time to improve these conditions, and the best the Navy and the nation can do is to hope that no national emergency will ever occur in coincidence with a fuel oil situation such as that of 1920.

In this connection, the United States is the only major naval power which contains within its borders a major supply of petroleum. Because of this, the other nations—England, Japan, France, Italy, and Germany—have been forced to provide a supply of fuel oil and other petroleum products in tanks at strategic locations. This is accomplished either by providing the storage as government property with government funds or by requiring, as a condition of operating in the country, that the oil companies maintain a minimum stock of products of the characteristics considered necessary. Probably the United States, with its magnificent deposits of petroleum and its unparalleled production and marketing of petroleum

products, is in a much worse position to take care of the initial demands for fuel oil, which a national emergency would impose, than any other country in the world. Of course, after the first few months, if those were successfully survived, the United States' position as regards Naval fuel oil supply would be impregnable. It must be hoped that those critical months will elapse without catastrophe.

FUEL OIL STORAGE.

In 1916 the Navy had a total fuel oil storage capacity, distributed to ten locations, of slightly more than 1,300,000 barrels. Emergency war construction added about 1,400,000 barrels of storage and added one additional location. Thus, at the end of the war, the total storage capacity for fuel oil under the Navy's control would have provided about a three months' supply at the 1920 rate. Most of this, however, was located as a part of the distribution system and could not be operated to provide much of an emergency reserve. All of the tankage built before the war and, except for Yorktown, that built during the war was intended to absorb the inequalities of fuel oil distribution between tanker deliveries from the refinery and barge or pump deliveries into naval vessels. As a reserve, of course, if the tanks ran dry at Guantanamo, for example, a tanker could have drained tanks at other locations to supply vessels at Guantanamo. That would have required the availability of tankers and would in a very short period have completely wrecked the distribution system.

Actually, any fuel oil reserve system must be combined with the distribution system. The elements of the combined systems are:

(*a*) A source of petroleum underground and under naval jurisdiction to replace the commercial underground supply when it fails or lags.

(*b*) An adequate source of petroleum under commercial control and production to meet current demand.

(*c*) An adequate supply of satisfactory fuel oil in tanks strategically located to tide the fleet over any temporary failure of the commercial production such as that of 1920 or to bridge the transition period while the Navy's underground reserves are being brought into operation.

(*d*) Adequate transportation facilities to provide for carrying fuel oil as needed from the commercial source or from reserve tankers to the distribution points.

(*e*) Adequate distribution facilities which include:

1. Shore storage at fleet operating bases,
2. Wharfage and pumping facilities at the shore storage locations,
3. Fuel oil barges to work between the shore storage and vessels of the fleet, and
4. Fleet tankers to accompany the fleet and provide fuel oil when the vessels are operating away from shore bases.

Of the above elements, the second, adequate commercial source and production, has always been available except for short periods. No actual shortage in this has ever been experienced, although the fear of imminent shortage has occasionally been felt. However, this element does not cancel the need for any of the others except the Navy's own underground source reserve. Notwithstanding this fact, that is the only other element which has been adequately provided for. The Navy's petroleum reserves, after passing through many vicissitudes, have now been secured as previously described and are adequate for the purpose intended.

It is in the elements where disaster might lie in the event of a sudden emergency that we are very poorly prepared. If no emergency ever arises where the security of the nation depends on a fleet campaign without preparatory notice, the lack of these elements will never be felt. This country, with its vast resources, can easily take care of any situation as regards fuel oil if given a few months' time.

This proposition was definitely realized by the Navy almost from the adoption of fuel oil until after the wave of unfavorable publicity which attended the Petroleum Reserve investigation in 1923. Since that date, until very recently, apparently the subject has been considered too hot to discuss. Whatever the reason, the Navy campaigned aggressively for shore storage and tankers from the end of the war until 1923 and from that date seemed to accept the inevitable and trust that future emergencies would take care of themselves without disaster.

The 1916 Fuel Oil Board had included in its findings and recommendations that the Navy should have reserve tankage equal to twice the annual consumption. The board estimated that the annual consumption would reach ten million barrels in 1927. This prediction was based on the completion of vessels authorized by the 1916 Navy Bill. Although conditions changed very greatly, ten million barrels as an annual rate and twenty million barrels as a reserve supply is today a reasonable figure, with one additional provision.

It has been estimated, with no real basis for estimating, that wartime consumption of fuel oil would be from three to four times the peacetime use. That is, the two years' supply would be reduced to a six or eight months' supply for wartime. The figure is adequate to allow time under any conceivable circumstances to permit the country to arrange an adequate supply of fuel oil for a war of any duration. However, the amount is none too large and, for that reason, it should be considered as applying only to the need in one ocean. The additional provision mentioned above is that there should be *in each ocean* or rather *on each coast* a reserve supply of fuel oil equivalent to two years' peacetime consumption. The fleet may move for an emergency camgaign into either ocean. The shore-built storage tanks cannot accompany it. With the necessity of providing for both coasts it would be dangerous to depend on hauling fuel oil from Pearl Harbor or Puget Sound to supply the fleet on a campaign in the North Atlantic. The result of this discussion is the indication that the Navy's reserve fuel oil storage requirement is about twenty million barrels located at Atlantic naval bases and an equal amount at Pacific bases.

This estimate agrees fairly closely with the recommendations of the General Board, which governed the Navy's actions in the first few years after the war. In July, 1920, the General Board recommended that the total reserve storage be 34,000,000 barrels at specified locations. This was just a repetition of previous recommendations. For the fiscal year 1921, to commence the construction of the additional reserve storage required, the Navy asked for $2,050,000 to construct storage facilities for fuel oil at Puget Sound and Pearl Harbor. These two locations were considered to merit the highest priority. Justification of this item in the

budget devolved upon the Chief of the Bureau of Yards and Docks, since money for Public Works came under his jurisdiction.

The fate of this matter appears to have been settled, in part at least, by the testimony of Admiral Parks, Chief of the Bureau of Yards and Docks. The following excerpt from the testimony is of interest as indicating how such things are sometimes determined:

Hearings before the House Naval Affairs Committee on February 25, 1920.

"Item: Depots for Fuel Oil—Puget Sound, $1,050,000; Pearl Harbor, $1,000,000.

Admiral Parks: That is very much less than the planning section of operations thought necessary.

Mr. Browning: Are you talking about Puget Sound?

Admiral Parks: All of them.

Mr. Padgett: Take them up in detail and tell us what you have got at Puget Sound.

The Chairman: And how much money you have spent there.

Admiral Parks: There are 11,900,000 gallons capacity at Bremerton now.

The Chairman: How much has that cost?

Admiral Parks: I will insert those figures in the record—approximately $530,000. The exact amount will not be known until an open contract is adjusted.

Mr. Padgett: What would be the capacity with the additional appropriation of $1,050,000?

Admiral Parks: That would be 85,000 tons more. That is based on using steel tanks.

Mr. Padgett: You have the other in gallons. What does a ton represent in gallons?

Admiral Parks: It is a 2,000-pound ton and there are 55 to 56 pounds to the gallon.

The Chairman: There are about 375 gallons to the ton?

Admiral Parks: Between 375 and 380.

The Chairman: How many gallons will that give you?

Admiral Parks: That would be between 32,000,000 and 33,000,000 gallons. That in steel tanks will take practically the whole area at the northwest end of the yard that has been purchased during the last year, allowing such a space that the berms

will take the whole capacity of the tank that leaks. We have got to lay it out in spaces large enough so that if a tank bursts or leaks the whole capacity of that tank will be inclosed within the berm surrounding the tank.

Mr. Padgett: So as not to endanger the others?

Admiral Parks: Yes.

Mr. Padgett: I would like to ask what storage capacity you have at San Francisco, Mare Island.

Admiral Parks: We have only one small tank at the training station, 79,000 gallons, at San Francisco.

Mr. Padgett: That is on Goat Island; that is, the training station?

Admiral Parks: Yes.

Mr. Padgett: What about Mare Island? What is the storage capacity there?

Admiral Parks: At Mare Island the capacity is 4,200,000 gallons, but one of those tanks is being used for water storage at the present time. That is a third of it, and we have an appropriation to increase the storage at Mare Island.

Mr. Padgett: How much will you increase it?

Admiral Parks: I have been asked to submit that matter to the committee this time, to get authority to expend the money available for fuel oil storage at Mare Island, at Tiburon, that is put in at California City.

Mr. Britten: Why?

Admiral Parks: So the large ships can get oil from the station.

Mr. Britten: Large ships can very easily go up the channel to Mare Island.

Admiral Parks: Tiburon is down below the shoal.

Mr. Padgett: With the increase proposed, what will be the capacity at either plant?

Admiral Parks: If we put it at Tiburon, I am recommending steel tanks, and the steel tanks ought to cost us about 95 cents a barrel for that storage. We have $400,000 available.

Mr. Padgett: That would give you, in round numbers, 400,000 barrels. How many gallons would that be?

Admiral Parks: That would be about 16,200,000 gallons.

Mr. Britten: How long will it take to complete the fuel oil storage in Pudget Sound, on a rush order with the facilities we

have in the country now, for which $1,050,000 is estimated—90 days?

Admiral Parks: The steel industry is in bad shape for delivery at the present time.

Mr. Britten: Suppose you could get the plates right away, would you do that in 90 days?

Admiral Parks: Ninety days.

Mr. Britten: Do you not think all those items which are purely for surplus storage purposes can be left out of the bill for the time being?

Admiral Parks: I have been very strongly urged to insist on the fuel oil storage to the extent that we have it shown here. We have to take into consideration that there is a tremendously large storage capacity on the east side of San Francisco Bay, of the commercial combination, and we know probably that combination will prevent us from getting fuel there during time of peace in the immediate future. I can not myself see why we could not get our oil there. But there is just the possibility if we have not enough storage ourselves to take care of 30 days or 60 days, the price will be put up on us to more than we ought to pay.

Mr. Britten: War on the Pacific is not likely to come as quickly as that.

Admiral Parks: But this is due to lack of competition in price.

The Chairman: If all these items you have included in this paragraph should remain in the bill and we appropriate the amount asked for, $2,135,000, how much storage will we have, and how long will that storage serve the Navy? Most of that is on the Pacific. It would be several years, would it not? You can insert that answer in the record.

Admiral Parks: No, the use of oil is pretty rapid at the present time. The Bureau of Supplies and Accounts gave the figure for the use of fuel oil and my recollection is that they are pretty large figures, about 34,000,000 gallons per month. The storage would amount to 152,000,000 gallons.

Mr. Padgett: According to the figures, you give you have already between 29,000,000 and 30,000,000 gallons, including the appropriation available for Mare Island. Could you not make out with that, considering the proximity on the Pacific Coast to the

California oil fields? You are pretty close to those fields out there, and having a capacity already constructed and appropriated for of storage for about 30,000,000 gallons; would not that run you?

Admiral Parks: There is another point that has been brought up, that we ought to be able to store a considerable quantity of reserve.

The Chairman: That is what I asked you about.

Admiral Parks: I think the figure given the bureau for a two years' reserve, with concrete tanks at $1.80 per barrel, figured something like $59,000,000 for investment.

Mr. Padgett: As a matter of fact, we have no capacity for reserve on the Pacific Coast in oil, and I was considering whether we could not postpone the reserve matter this year and just look after the immediate needs, and also whether the capacity you have already and the appropriation already made, providing for 29,000,000 or 30,000,000 gallons, with the proximity to the oil supply, would not take care of the Navy out there until we could get another supply.

Admiral Parks: That looks like a reasonable way of looking at it.

Mr. Padgett: I want to ask you another question. Have you got any oil storage at San Diego, and if so, how much?

Admiral Parks: We have a steel tank of 2,100,000 gallons capacity and a new concrete tank that I think is pretty nearly ready now of about 4,800,000 gallons capacity.

Mr. Padgett: That would give you over 6,000,000 gallons?

Admiral Parks: Nearly 7,000,000 gallons there.

The Chairman: That would run it up to nearly 37,000,000 gallons on the coast and that looks as if it would give us a pretty good supply, considering the close proximity of the oil fields out there.

Admiral Parks: That was the way it looked to me, but the point was made that the combination of prices might make it disadvantageous to us.

Mr. Padgett: Are prices going up any higher than they are right now?

Admiral Parks: Our right to commandeer will cease shortly.

The Chairman: Have we not oil properties in California that we can develop?

Admiral Parks: I do not know. We are appropriating $10,000 a year.

Mr. Padgett: Under a decision of the Supreme Court in one of the railroad cases a large oil area was saved to the Government. There was another case in dispute, but it is not developed. For the immediate present, that would not answer because we have got to get it from a developed field. But with practically 37,000,000 and being so close to the oil fields, it seems to me we can do without the reserve.

The Chairman: You made a statement in regard to the amount of oil we used in a year. Did you mean to describe it by barrels or gallons?

Admiral Parks: I think it is barrels, 34,000,000. It should have been about 34,000,000 gallons per month.

Mr. Britten: Would you feel inclined to withhold going ahead with the other storage item you spoke of until next year, prior to which the Navy Department might have settled on its policy for a base?

Admiral Parks: I feel inclined to do just that.

Mr. Britten: That looks like a good proposition to me."

And so the question of reserve fuel oil storage was disposed of. Perusal of the above-quoted testimony does not convince that the Navy's case was very ably presented. Possibly a perfect presentation would have had no better success, because the Congress at that time had no anxiety about an emergency or war in the near future and it was determined to cut the expenditures of the federal government to the absolute minimum.

The 1921 appropriation bill did not provide for the reserve storage which the Navy felt that it must have. Under date of December 4, 1920, the following letter was addressed by the Secretary of the Navy to the Speaker of the House of Representatives:

" My dear Mr. Speaker:

The Department, after careful investigation and consideration relative to the use of obsolete naval vessels as floating storage for fuel oil, considers it very desirable to convert certain obsolete vessels into fuel-oil barges, in view of which it is recommended that the following item be included in the naval bill for the fiscal

year 1922, under the appropriation for the Bureau of Construction and Repair:

'*Provided,* That the Secretary of the Navy is authorized to make expenditures from the appropriation "Increase of the Navy, Construction and Machinery," in an amount not to exceed $6,000,000, for the conversion of the *Kentucky, Alabama, Illinois,* and *Wisconsin* into fuel-oil barges, *Provided, however,* That the Secretary is authorized to substitute other obsolete naval vessels for the purpose if it should appear to be to the best interests of the department.'"

The above proposal had come from the General Board. Whether it was put forward because of the committee's refusal to provide the shore storage previously requested cannot be stated. This charge was made and denied during the hearings on the proposal. These hearings brought out that the $6,000,000 requested would provide floating storage (not self-propelled) equivalent to what could be provided by $1,000,000 worth of oil barges; $2,000,000 worth of self-propelled tankers; or $240,000 worth of shore tanks. The hearings did not disclose any real merit to the proposition at all and naturally it was turned down. Its submission could not have made the committee feel any more kindly toward the Navy's storage problem.

Congress' refusal to provide the reserve fuel-oil storage which the responsible military heads of the Navy felt so definitely was required laid the foundation for the next and most effective step. The basic explanation of the action which the Navy Department took in connection with the Petroleum Reserves can be found more clearly in the following letter than in any original explanation which might be made here. The letter was addressed by the Assistant Secretary of the Navy, Franklin D. Roosevelt, on June 4, 1920, to Senator Fred Hale in answer to an inquiry as to where the faults in the organization of the Navy Department lay:

"Frankly, what is the most serious trouble with the Navy now, as it has been in the past, is Congress. The system of making legislation and appropriations is not only archaic, but would put any private business firm into bankruptcy in a month. The method of dealing with any one of the naval appropriation bills will, I am

sure, convince you of this. The Navy has in the past been treated altogether too much, as the tariff used to be, as a local issue. Allow me to cite as an example the amendments made by the Senate Naval Affairs Committee to the present appropriation bill. I am convinced, after seven years' association here, that the legislative and appropriating methods of Congress have compelled far too many of our naval officers to resort to similar political methods, because it is the only way to accomplish results. This is, of course, entirely wrong. The Navy has always had to lead a hand-to-mouth existence, interspersed with investigations, hastily gotten up plans, makeshift policies, and a general spirit of time-serving to meet the political conditions of the hour."

The above letter was not written with the fuel oil storage question directly in mind. It certainly covers the situation. The General Board had recommended a policy as regards provision of a reserve of fuel oil in tanks ready for use. Many responsible naval officers considered it vital. The matter had been presented to the congressional committee with which the Navy had to deal and was turned down. It was turned down on only one basis—economy. It is true that this action of Congress relieved the Navy Department of responsibility, since the Navy must at any time carry out its functions with whatever tools Congress has provided.

So vital did this matter seem to some naval officers that they could not accept the decision of Congress as final. After the storage tank proposition was turned down, a substitute (partial at least) plan of providing floating storage was submitted. Failure of this plan to meet approval did not close the door. The storage must be built. The way was found in a clause in the naval appropriation act for the fiscal year 1921, enacted on June 4, 1920. This clause read:

"That the Secretary of the Navy is directed to take possession of all properties within the naval petroleum reserves as are or may become subject to the control and use by the United States for naval purposes, and on which there are no pending claims or applications for permits or leases under the provisions of the act of Congress approved February 25, 1920, etc., to conserve, develop, use, and operate the same, in his discretion, directly or by contract,

lease, or otherwise, and to use, store, exchange, or sell the oil and gas products thereof and those from all royalty oil from lands in naval reserves, for the benefit of the United States: *And provided further,* That the rights of any claimant under said act of February 25, 1920, are not affected adversely thereby: *And provided further,* That such sums as have been or may be turned into the Treasury of the United States from royalties on lands within the naval petroleum reserves prior to July 1, 1921, not to exceed $500,000 are hereby made available for this purpose until July 1, 1922: *Provided further,* That this appropriation shall be reimbursed from the proper appropriations on account of the oil and gas products from said properties used by the United States at such rate, not in excess of the market value of the oil, as the Secretary of the Navy may direct."

Of interest to the fuel oil storage proposition was the authorization contained in the above act for the Navy to *store* the products of the reserves whether produced by the Navy or received as royalty. Since the Navy owned a very small amount of tankage, this provision was not of much value unless properly interpreted. The Judge Advocate General of the Navy held that the authority to "store" was broad enough to permit the exchange of any oil from the reserves which came into the Navy's possession for products "contained in tanks." That was the answer needed.

The Navy had fought a long fight to obtain and hold a reserve of petroleum underground. It had unsuccessfully fought to obtain an additional reserve of fuel oil stored in aboveground tanks, available for immediate use. Both were vitally needed. Evidence was now available which convinced many naval officers that the cherished underground reserve was being lost through drainage and that it would be but a matter of time before the Navy would have no reserve of any value and would have nothing to show for having had one.

The answer seemed quite apparent. Of the two kinds of reserves which it needed, Congress had provided but one. That was being lost through the application of natural laws and little could be done to prevent the loss. However, the act of June 4, 1920, had placed in the Navy's hands the authority to save as much from the loss as possible and to convert it to the second type of vitally

needed reserve. True, the Navy wanted and needed both reserves, but either one was better than none. It was through this kind of reasoning that many naval officers were brought into support of the leasing of naval petroleum reserves which later became the "Teapot Dome" and "Elk Hills" scandals.

The act of June 4, 1920, appropriated $500,000 for carrying out the purposes of the act. Since "storage" of petroleum products was one of these purposes, it was held that this money could be expended to build oil tanks. Of the places on the General Board's plan where fuel oil reserve storage was needed, the Canal Zone was near the top of the list. This half million dollars was used to build 150,000 barrels of fuel oil storage tanks at each end of the canal and some storage at Coco Solo for gasoline and lubricating oil. The total plan required the construction of a total of 47 million barrels capacity of fuel oil storage tanks, so it is apparent that the small sum appropriated hardly scratched the surface.

The remainder would have to be cared for under the exchange provision of the act. The Pan American Petroleum and Transport Co. had obtained the lease of the California reserves and to that company was given the further exchange contract to construct and fill the storage required on the Pacific Coast. The Mammoth Oil Company held a corresponding position in the Wyoming reserves and it was to provide the required filled storage on the Atlantic Coast. The entire plan was drawn up and priorities assigned to the storage for each location. Pearl Harbor drew the number one position in the Pacific, and Portsmouth, New Hampshire, on the East Coast.

Pearl Harbor was by far the largest single project in the entire plan. The first contract there was for 1,500,000 barrels of fuel oil storage. This was completed and followed with an additional 2,500,000 barrels of fuel oil plus other tankage for lubricating oils and gasoline. Completion of Pearl Harbor would have seen Pudget Sound taken up next on the West Coast and Portsmouth would have been followed by Boston Harbor.

Puget Sound and Boston were never reached. The suspicions of the Senate had been aroused and the investigation in that body began before the Pearl Harbor and Portsmouth storage had been completed. Further steps in completing the total plan were never

undertaken. Including the tanks built in the Canal Zone, the interpretation of the act of June 4, 1920, provided a total of 4,600,000 barrels of fuel oil storage. This compares with a total of about 2,700,000 barrels provided by direct action of Congress in the entire period from 1909 through 1936.

Measured in barrels of fuel oil storage, the actions of the Navy Department in utilizing the petroleum reserves resulted in a real achievement. Measured in military importance the final answer cannot be written. Provision of an adequate reserve of fuel oil, stored in tanks, for immediate use in the event of an emergency was recognized as a military necessity from shortly after 1909 until 1923. Apparently because of fear of the possible consequences of congressional reaction if the fuel oil question was reopened after the Senate investigation, the Navy, publicly at least, dropped the entire matter after 1923. The need was just as great and is today of paramount importance. Failure to provide this storage has resulted in a saving to the federal treasury. At the same time, the lack of this reserve, although it has prevented easy planning, has not been responsible for any national disaster. It never will be if the Navy is never to engage in a major war, and that is the only argument, except economy, which can be raised against the need for reserve storage. Since the availability for war is the Navy's reason for existence, provision of the money for the purpose cannot reasonably be withheld.

Since a lack of sufficient fuel oil of the proper kind and in the proper location might remove the entire fleet from a campaign, which, in turn, might or might not lead to its destruction, with the consequent effect of such loss on the nation, this question must be held in the foreground until a satisfactory answer is found. Fuel oil for the fleet is of vastly greater importance than a horseshoe nail, yet the effect of that lost nail, as portrayed in the classic rhyme, in causing the loss of a battle may easily be repeated at some future date by the lack of a fuel oil reserve.

TANKERS.

As a portion of fuel oil facilities required by an oil-burning Navy, tankers are needed for two distinctly different purposes. Both of these needs have been long recognized. They have been

provided for almost as inadequately as the reserve storage has. The two types of vessels needed are a commercial-type tanker for picking up cargoes of fuel oil at the refinery source and carrying it to fuel oil depots and reserve storage tanks, strategically located at fleet operating areas. This type of tanker should have as large capacity as possible and need not be very fast. The second type must operate with the fleet at sea and, in addition to carrying fuel oil, should be capable of carrying lubricating oils and gasoline, if possible. It must be provided with facilities for fueling all types of naval vessels, either in port or while underway at sea. This fleet tanker must have sufficient speed to keep up with the fleet at sea, which means sufficient to permit it to regain position after it has been necessary for it to slow down for fueling operations at sea during an advance. Its speed should also permit it to return to a source of supply to refill its tanks and then rejoin the fleet with as little delay as possible.

Prior to the World War the Navy had had only the second type of tankers. Before and during the war a total of six of these vessels, all with a designed speed of fourteen knots, were constructed by the Navy to Navy specifications. These are the only vessels of the type ever to be so built. They were completed at Navy Yards between 1915 and 1921 and are all still in service, with one exception. The *Maumee* was built as an experimental Diesel engine propelled vessel and proved a failure. No steps were ever taken to reengine her to make her satisfactory for service, so actually only five fleet oilers were ever satisfactorily built. Since there have been no replacements for any of these vessels, it is apparent that they were well built for the service intended.

The construction of additional fleet oilers was probably prevented in part by the same spirit which led to naval disarmament attempts, but it was stopped by a lack of understanding of the differences between the two types. The cargo tanker which the Navy had not had before the war was built in considerable numbers by the Shipping Board as a part of its war program. All of these vessels were, in so far as the Navy was concerned, of the first type and were not suitable for service as fleet oilers. Their speed was only ten knots. Of the Shipping Board vessels, three with a capacity of 8,850 barrels each, and 8 of a larger size, 11,145 barrels

were turned over to the Navy. To many it must have seemed that so many tankers would take care of the Navy's needs for many years to come, if not for all time. The fact that the eleven vessels were of very limited naval application was entirely overlooked. They are distinctly the cargo type of tanker, and thus can be used by the Navy only for transporting a cargo between fixed points. They cannot be used to carry oil to a moving destination such as a fleet.

The Navy's somewhat sporadic efforts to obtain additional and replacement fleet oilers met with no success until 1937, when one such vessel was authorized. Four more were authorized a year later and money was appropriated to begin the first three of these five vessels. Due to a desire on the Navy Department's part to save as much money as possible on naval construction, decision was made to acquire commercial tankers instead of to design and build real fleet oilers. It was possible to do this and still obtain the speed considered necessary for a fleet oiler because the Maritime Commission under its legal authority was paying the difference in cost between about twelve knots and sixteen knots in certain commercial tankers which were being built. No oil company in the United States has found any commercial need for oil tankers which can make in excess of twelve knots and that is the maximum speed of practically the entire tanker fleet of the United States merchant marine. However, the three tankers being acquired by the Navy and nine others of the same kind will be capable of sixteen knots, which will, in so far as speed is concerned fit them for use as fleet oilers.

The only plans which the Navy can make for the supply of fuel oil in the event of a war emergency must depend on the utilization of commercial tank vessels. At the present time this cannot lead to a very satisfactory solution. In the near future there will be a few fast enough vessels available so that probably a satisfactory plan can be evolved as far as the Navy's direct interests are concerned. However, how about the present owners and operators of the commercial tankers? The oil industry has built itself into the economic and social structure of the United States so thoroughly that any dislocation of the supplies of petroleum products from their usual commercial markets is bound to have a

very serious effect. In taking care of these markets, the oil tanker plays a very important part. Practically all of the petroleum used in the northeastern part of the country must be imported from other countries or from other parts of the United States. Even if the entire demand could be satisfied by domestically produced petroleum, the tanker would be relieved of a very small part of its work. At least 90 per cent of the oil which moves into the heavily populated northeastern states comes in by tanker and there are not nearly enough pipelines and tank cars in existence to permit a very great relief of the tankers.

With the commercial situation as it exists, there can be little doubt that a major emergency involving a naval campaign will be reflected in a condition approaching distress in areas which have become highly dependent on petroleum products, but which depend on tanker transport for their supply. The Navy will have to satisfy its needs from the commercial fleet unless, before the emergency arrives, they are properly taken care of. The oil companies will then have to accommodate their needs to what is left until more can be constructed. If this can be done without adding an oil and gasoline famine as one of the horrors, or at least great discomforts of war, much credit will accrue to the planners.

Conclusion.

The above completes an attempt to cover the first thirty years of the Navy's thirty-five-year fuel oil history. Most of the high lights have been sketched and the more spectacular ones described at length. Occasionally, where the facts were known to the author, the history has been extended beyond the year 1934, when his personal contact with the matter ended. The history cannot be considered as complete beyond 1934.

The peculiar fact which is disclosed by the history is that basically there are no new problems connected with fuel oil. Practically every one of them was fully recognized at the very beginning and has remained unchanged except as the movements of time and the change of circumstances and conditions have modified them. With all that, practically nothing has been accomplished which would insure that fuel oil will not become one of the Navy's worst headaches if war comes. Except for the underground petroleum

reserves, our fuel oil facilities, viewed as a whole, are not adequate to take care of normal peacetime needs without restriction on operations. Their expansion to take care of a probably quadrupled demand, spread over a much greater geographical area, will require the ultimate in intelligent planning and cooperation.

In order that this paper will not be ended on a morbid note, the author believes that the problem will be solved, as such things have been in the past, without approaching disaster to the nation. He is unable to reconcile himself to a system which places the extra burden of such solution on the shoulders of the first line of defence.

CALORIFIC VALUE-GRAVITY RELATIONSHIP OF FUEL OILS.

By Cyrus Beck.*

Several formulas have been presented representing the relationship between the calorific value of fuel oils and their gravities. No formula has yet been offered that will apply to all types of fuel oils. A given equation will, of course, fit best the type of oil for which it was deduced.

The BTU/lb.-API degree at 60 degrees F. relationship of fuel oils of interest to the United States Navy, the group of oils satisfying Navy specifications, has been determined periodically.

The original Naval Boiler Laboratory BTU-API formula was derived in 1933 from 49 oils, the 1935 formula from 50 oils. A new formula has been deduced from a study of all the oils delivered to the Naval Boiler Laboratory from June 1, 1935, to October 1, 1938. Two hundred and sixty-six (266) fuel oils were considered or more than five times as many as were used in deducing the two earlier equations. This gives added weight to the new formula presented by the author.

Method of Test.

The BTU values were determined by a Parr Adiabatic Oxygen Bomb Calorimeter in the usual manner. The procedure employed was identical with that recently published by the American Society for Testing Materials. The gravities of most of the oils were obtained by hydrometers graduated in API degrees. Gravities of a few oils were determined by pycnometer and converted to API degrees by the following formula:

$$\text{API degrees} = \frac{141.5}{\text{Specific Gravity } 60°/60°\text{F.}} - 131.5$$

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The oils, in order of increasing API gravities, are presented in Table 1, together with their pertinent characteristics. Most of the oils tabulated therein are Navy-grade fuel oils, either East or West Coast deliveries. Other grades of fuel oils were included in computing the formula, but in each case special note of the particular oil is made. The latter fuels are designated in Table 1 by letters representing their bunker grades.

Method of Calculation.

The BTU-API relation was determined by the method of least squares, using the ordinary statistical formulas to be found in standard text books on the subject.* The coefficient of correlation and the standard error of estimate were also calculated, since they are of interest in gauging the validity of the new formula.

Computations were based on the conception of class intervals. In the case of BTU's the class interval is equal to 100 BTU. The API class interval was chosen to be 2 degrees API. The error introduced by this method is very small.

For reference, the zero point for the BTU values was taken at 18,700, which is the midpoint in the interval 18,749-18,650 BTU. The zero point for the API gravity values was taken at 20, the midpoint of the interval 19.00-20.99 degrees API.

The correlation table and the computation of values for curve fitting are shown in Table 2. The letter f stands for the number of oils with values falling within a particular interval. The interval number—either plus or minus—is represented by d'. The letter X' indicates the API interval value for any block, while Y' has the same meaning with regard to BTU. In connection with f' (X'Y'), f' stands for the number of oils in any given block.

The number of oils is represented by N; Σ has its usual meaning of summation. From the correlation table, the following symbols are satisfied:

$$N = 266 \qquad \Sigma' (X')^2 = 3921$$

$$\Sigma' (X') = -821 \qquad \Sigma' (Y')^2 = 3472$$

$$\Sigma' (Y') = -670 \qquad \Sigma' (X' Y') = 3360$$

* "Statistical Methods," F. C. Mills; "Theory of Statistics," G. Udny Yule.

Ref. No.	N.B.L. No.	Degrees API At 60°F.	B.T.U. Per Lb.	B.T.U. Per Gal.	Bunker: Grade (See Note)
1	B-1531	2.2	17853	157303	B
2	B-1579-2	2.5	17877	157810	B
3	B-1574	4.0	18052	156944	B
4	B-1530	4.2	17948	155825	B
5	B-1535	4.3	17915	155395	B
6	B-1570-1	4.4	17972	155860	B
7	B-1570-4	4.6	17996	155953	B
8	B-1532	5.1	18022	155694	B
9	B-1570-3	5.6	18109	155689	B
10	B-1616	7.2	18064	153472	B
11	B-1837	8.2	18302	154396	B
12	B-1738	8.39	17965	151355	B
13	B-1538	8.5	18075	152029	B
14	B-1779	8.5	18243	153570	B
15	B-1616	8.7	18161	152804	B
16	B-1642	8.8	18185	152754	B
17	B-1847	9.1	18102	151765	B
18	B-1572	9.3	18280	153650	B
19	B-1634	9.42	18244	153534	B
20	B-1617	9.70	18213	151982	B
21	B-1585	10.00	18261	150078	B
22	B-1637	10.25	18376	152778	NE
23	B-1689	10.35	18367	152467	NE
24	B-1818	10.42	18266	151644	NE
25	B-1657	10.45	18408	152823	B
26	B-1626	10.50	18221	151216	B
27	B-1700-5	10.60	18378	152559	B
28	B-1718	10.7	18132	150260	NE
29	B-1846	10.75	18296	151582	B
30	B-1595	11.00	18580	153160	B
31	B-1836	11.00	18257	150985	B
32	B-1682	11.00	17865	147727	R
33	B-1599	11.05	18300	151286	D
34	B-1774	11.05	17957	148451	R
35	B-1657	11.09	18426	152273	B
36	B-1746	11.10	18494	152950	NE
37	B-1660	11.10	18305	151873	NE
38	B-1699	11.20	18275	150915	NE
P 39	B-1694-2	11.25	18348	151463	B
40	B-1639	11.40	18427	151994	B
41	B-1641	11.40	18299	150894	NE
42	B-1839	11.40	18277	150072	B
43	B-1830	11.40	18163	149772	NW
44	B-1756-B	11.40	18297	150880	O
45	B-1498	11.47	18402	151784	NE
46	B-1602	11.48	18290	150746	B
47	B-1821	11.5	18154	149607	NW
P 48	B-1709	11.5	18174	149790	B
49	B-1501	11.52	18400	151660	NE
50	B-1604	11.55	18243	150286	NW
51	B-1494	11.55	18435	151894	NE
52	B-1957	11.60	18380	151359	NE
53	B-1692	11.60	18435	151812	NE
54	B-1707	11.60	18510	152430	B
55	B-1723	11.60	18365	151240	B
56	B-1799	11.60	18280	150048	NW
57	B-1428	11.62	18396	151528	NE
58	B-1656-A1	11.65	18467	152867	B
59	B-1640	11.65	18409	151543	B
60	B-1599	11.65	18360	151179	B
61	B-1597	11.66	18390	151367	B
62	B-1683	11.70	18360	151684	B
63	B-1598	11.70	18375	151206	O
64	B-1708	11.70	18194	149718	NW
65	B-1705	11.70	18194	149718	NW
66	B-1714	11.75	18348	150880	B
67	B-1698	11.80	18497	152159	B
68	B-1822	11.80	18330	150728	B
69	B-1704	11.81	18380	150660	NW
70	B-1703	11.83	18308	150510	NW
71	B-1588	11.86	18293	150366	B
72	B-1582	11.87	18406	151889	NE
73	B-1584	11.87	18434	151827	NE
74	B-1606	11.90	18451	151630	NE
75	B-1788	11.90	18403	151840	B
76	B-1647	11.91	18380	151089	B
77	B-1579	12.00	18223	149647	NW
78	B-1696	12.01	18230	149718	B
79	B-1577	12.02	18454	151847	B
80	B-1599	12.06	18360	150468	B
81	B-1576	12.07	18458	151819	B
82	B-1587	12.07	18599	152660	B
83	B-1581	12.10	18245	149718	B
84	B-1639	12.10	18360	150662	B
85	B-1643	12.10	18483	151179	NE
86	B-1726	12.10	18420	151166	NE
87	B-1513	12.12	18412	151052	NE
88	B-1518	12.12	18385	150830	NE
89	B-1529	12.12	18499	151784	NE
90	B-1534	12.15	18227	149516	B
91	B-1712	12.15	18407	150993	NE
92	B-1595	12.20	18495	151672	B
93	B-1685	12.21	18322	150240	B
94	B-1792-F	12.21	17920	146890	NE
95	B-1511	12.22	18395	150839	NE
96	B-1592	12.23	18420	151048	B
97	B-1657	12.27	18543	151974	B
98	B-1594	12.28	18393	150754	B
99	B-1597	12.30	18437	151095	B
100	B-1490	12.30	18447	151173	NE
101	B-1491	12.30	18463	151157	NE
102	B-1542	12.32	18471	151391	NE
103	B-1698	12.37	18390	150905	NE
104	B-1590	12.40	18404	150715	B
105	B-1580	12.43	18415	150764	B
106	B-1671-A1	12.46	18240	149313	B
107	B-1725	12.50	18387	150460	O
108	B-1737	12.50	18588	152100	NE
109	B-1686	12.58	18598	152113	NE
110	B-1654	12.60	18391	150468	NE
111	B-1772	12.60	18334	149940	NW
112	B-1771	12.70	18465	150899	B
113	B-1612	12.70	18381	150210	NE
114	B-1653	12.70	18588	150867	NE
115	B-1684	12.75	18531	151384	B
116	B-1736-A1	12.75	18416	150
117	B-1819	12.75	18630	150
118	B-1648	12.80	18549	151
119	B-1662	12.87	18578	151
120	B-1703	12.90	18364	149
121	B-1788	13.00	18364	149
122	B-1703-2	13.03	18585	150
123	B-1601	13.05	18571	150
124	B-1667	13.08	18618	151
125	B-1563	13.10	18628	151
126	B-1682	13.10	18795	153
127	B-1674	13.10	18481	150
128	B-1778	13.10	18586	150
129	B-1588	13.13	18529	150
130	B-1591	13.20	18400	149
131	B-1598	13.28	18650	149
132	B-1702-B	13.28	18615	149
133	B-1711	13.30	18753	150
134	B-1691	13.33	18280	149
135	B-1814	13.35	18415	149
136	B-1685	13.36	18278	149
137	B-1580-B	13.38	18670	150
138	B-1633	13.40	18656	150
139	B-1840	13.40	18376	149
140	B-1636	13.45	18685	150
141	B-1634	13.50	18648	150
142	B-1713	13.50	18754	150
143	B-1795	13.50	18581	149
144	B-1764	13.50	18573	150
145	B-1580	13.52	18593	150
146	B-1624	13.60	18378	149
147	B-1644	13.61	18484	149
148	B-1694-A1	13.62	18574	150
149	B-1702	13.65	18537	150
150	B-1780	13.65	18404	149
151	B-1781	13.70	18109	148
152	B-1782	13.70	18598	150
153	B-1699	13.82	18433	149
154	B-1625	13.90	18303	149
155	B-1788	14.00	18465	149
156	B-1781	14.05	18335	149
157	B-1682	14.10	18621	150
158	B-1786	14.10	18422	149
159	B-1787	14.10	18458	149
160	B-1794-B1	14.15	18186	149
161	B-1626	14.20	18598	150
162	B-1652-B1	14.28	18703	150
163	B-1560	14.30	18441	149
164	B-1693-A1	14.30	18590	150
165	B-1758	14.30	18424	149
166	B-1827	14.35	18615	150
167	B-1580	14.38	18577	150
168	B-1656	14.40	18423	149
169	B-1638	14.40	18215	149
170	B-1647	14.40	18695	150
171	B-1804	14.40	18579	149
172	B-1674-B1	14.42	18460	149
173	B-1578	14.45	18486	149
174	B-1803	14.70	18650	149
175	B-1798	14.70	18584	149

TABLE - 1

NE - Navy Grade contract fuel oil -
NW - Navy Grade contract fuel oil -
B - Bunker "B" oil
D - Diesel fuel oil
E - Distillate fuel oil
F - Foreign fuel oils

B.T.U. Per Lb.	B.T.U. Per Gal.	Bunker Grade (See Note)	Ref. No.	H.B.L. No.	Degrees API At 60°F.	B.T.U. Per Lb.	B.T.U. Per Gal.	Bunker Grade (See Note)	Ref. No.	H.B.L. No.	Degrees API At 60°F.	B.T.U. Per Lb.	B.T.U. Per Gal.	Bunker Grade (See Note)
18416	150440	O	176	H-1613	14.80	18411	148300	NW	236	H-1514	20.07	18807	146806	S
18430	150189	NE	177	H-1532	14.80	18412	148509	S	237	H-1522	20.34	19000	147840	NE
18549	151473	S	178	H-1820	14.80	18685	150024	NE	238	H-1529	20.60	18985	147077	NE
18695	152820	NE	179	H-1832	14.80	18474	148808	S	239	H-1532	20.76	18938	146868	NE
18384	149869	NE	180	H-1720	14.85	18478	148790	NW	240	H-1544	20.81	19013	147187	NE
18364	149758	S	181	H-1776	14.90	18654	150146	NE	241	H-1546	20.81	19030	147218	NE
18585	151584	O	182	H-1789	14.90	18465	148620	NW	242	H-1571	20.87	18987	147144	NE
18571	151428	R	183	H-1733	14.95	18488	148780	NW	243	H-1564	20.91	18954	146852	NE
18619	151731	S	184	H-1601-A	15.00	18485	148811	S	244	H-1747	21.40	18758	144563	S
18628	151813	NE	185	H-1630	15.00	18395	147648	NW						
18795	1499217	S	186	H-1781	15.00	18675	150822	NE	245	H-1798	21.40	19160	147647	S
18491	1507941	NE	187	H-1768	15.00	18675	148613	NW						
18528	151002	S	188	H-1676	15.05	18444	148308	NW	246	H-1829	21.60	19128	147163	S
18559	150404	NE	189	H-1721	15.20	18319	147160	NW	247	H-1581	21.68	19071	146751	NE
18400	149850	NW	190	H-1601-A	15.20	18450	148209	S	248	H-1768	21.90	19125	147130	S
									249	H-1773	22.00	18923	145853	F
18650	1497987	S	191	H-1727	15.30	18410	147780	NW	250	H-1515	22.40	18981	145319	S
18015	1466844	NE	192	H-1777	15.30	18446	148082	NE						
18953	1509860	NE	193	H-1841	15.30	18543	148885	NW	251	H-1778	22.92	18976	144778	S
18280	1487261	NE	194	H-1813	15.40	18572	148368	NW	252	H-1593-A	24.70	19275	145411	S
18415	1496061	NW	195	H-1699	15.41	19309	146638	NW	253	H-1716	26.40	19062	142280	S
									254	H-1748	27.70	18884	139761	S
18278	1466251	S	196	H-1681	15.42	18506	148418	F	255	H-1742	29.00	19182	140819	S
18670	1518431	NE	197	H-1695	15.45	18784	150689	NE						
18656	1517101	S	198	H-1669	15.45	18770	151530	NE	256	H-1741	31.00	19214	139323	S
18376	1496341	NW	199	H-1705	15.65	18647	149740	S	257	H-1543	31.33	19256	139338	NE
18625	1514211	S	200	H-1581	15.65	18567	148703	NW	258	H-1717	31.60	19305	139850	S
									259	H-1744	31.80	19334	139288	S
18644	1515801	S	201	H-1649	15.65	18987	148142	NW	260	H-1828	32.40	19404	139476	S
18354	1491601	R	202	H-1553	15.70	18586	148264	S						
18581	1493601	NW	203	H-1715	15.70	18630	147920	NW	261	H-1740	32.70	19439	139094	S
18573	1505401	NE	204	H-1722	15.73	18709	149456	S	262	H-1833	33.00	19411	139041	S
18593	1510871	S	205	H-1666	15.80	18762	150128	NE	263	H-1831	33.10	19412	138951	S
									264	H-1823	33.20	19453	139149	S
18378	1498741	NW	206	H-1958	15.80	18551	148406	NW	265	H-1745	36.5	19270	135181	S
18484	1496191	NE	207	H-1665	15.90	18781	150154	NE						
18574	150821	S	208	H-1661	15.95	18776	150058	NE	266	H-1743	38.5	19584	135301	S
18537	150500	NE	209	H-1688	15.96	18609	148783	NE						
18404	1494821	S	210	H-1811	15.95	18648	149307	NE						
18109	1469731	NE	211	H-1517	15.96	18551	148241	NW						
18598	150941	NE	212	H-1784	16.00	18832	148660	S						
18433	1494731	NE	213	H-1719	16.25	18509	147610	NW						
18703	1483461	NW	214	H-1673	16.30	18505	147540	NW						
18465	1495501	S	215	H-1734	16.30	18459	147270	NW						
18435	1490881	NW	216	H-1677	16.40	18469	147143	NW						
18621	150700	F	217	H-1730	16.50	18580	147930	NW						
18482	1490891	S	218	H-1552	16.50	18835	148588	S						
18458	1493381	S	219	H-1662	16.55	18733	147901	NE						
18186	1471431	NE	220	H-1745	16.60	18647	148356	NE						
18596	1564811	S	221	H-1736	16.60	18693	148782	S						
18703	1511761	S	222	H-1815	16.65	18580	147711	NW						
18441	1490001	NW	223	H-1538	16.65	18732	149589	S						
18520	1508441	NE	224	H-1658	16.67	18560	147897	NE						
18464	1498701	NW	225	H-1516	17.13	18542	147000	NE						
18615	1503901	S	226	H-1668	17.63	18685	1469701	NE						
18577	1500681	S	227	H-1668	18.38	18652	146847	NE						
18471	1487881	S	228	H-1550	18.38	18766	147520	NW						
18215	1469281	NE	229	H-1692	18.50	18819	147842	NE						
18645	1503901	S	230	H-1575	18.69	19087	149757	NE						
18579	1498781	NE	231	H-1696	18.70	18818	1496461	NE						
18460	1484801	S	232	H-1615	19.30	18826	147105	NE						
18486	1485671	NE	233	H-1607	19.45	18800	148753	NE						
18650	1487751	NW	234	H-1614	19.60	18827	146432	NE						
18564	1495701	NW	235	H-1578	19.65	18918	1475881	NE						

t Fuel oil - East Coast
t Fuel oil - West Coast

R - Fuel oil from storage
O - Fuel oil for special services
S - Fuel oil for special investigations
F - Specific gravity determined by pycnometer. Otherwise a hydrometer.

11

CORRELATION TABLE AND COMPUTATION OF VALUES FOR C

X = DEGREES API

Y = SFS FOR LB. FUEL OIL

MID POINTS	CLASS INTERVALS	f	d'	f(d')	f(d')²	2	4	6	8	10	12	14	16	18	20	22	24
						1.00	3.00	5.00	7.00	9.00	11.00	13.00	15.00	17.00	19.00	21.00	23.00
						2.99	4.99	6.99	8.99	10.99	12.99	14.99	16.99	18.99	20.99	22.99	24.99
						2	5	2	7	13	81	65	41	7	12	8	1
						-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2
						-18	-40	-14	-42	-65	-324	-195	-82	-7	0	+8	+2
						162	320	98	252	325	1458	847	164	7	0	8	4
19500	19549-19450	2	+8	+16	128												
19400	19449-19350	5	+7	+35	245												
19300	19349-19250	5	+6	+30	180												1
19200	19249-19150	5	+5	+25	125											2	
19100	19149-19050	4	+4	+16	64									1		2	
19000	19049-18950	9	+3	+27	81										2	2	
18900	18949-18850	4	+2	+8	16										2		
18800	18849-18750	15	+1	+15	15								5	5	4	1	
18700	18748-18650	15	0	0	0						2	15	5	1			
18600	18649-18550	55	-1	-55	55						4	19	10	1			
18500	18548-18450	58	-2	-78	156						14	15	11	1			
18400	18448-18350	67	-3	-201	603					3	38	17	6				
18300	18349-18250	27	-4	-108	432				1	3	17	3	3				
18200	18248-18150	22	-5	-110	550				3	1	12	1					
18100	18149-18050	8	-6	-48	288		1	1	2	2		1	1				
18000	18049-17950	6	-7	-42	294		2	1	1		2	1					
17900	17949-17850	4	-8	-48	384	2	2				2						
TOTALS		246	-	-670	3472	2	5	2	7	13	81	65	41	7	12	8	1

TABLE-2

ALUES FOR CURVE FITTING

22	24	26	28	30	32	34	36	38	TOTALS
.00	23.00	25.00	27.00	29.00	31.00	33.00	35.00	37.00	
99	24.99	26.99	28.99	30.99	32.99	34.99	36.99	38.99	
8	1	1	1	1	6	2	1	1	200
+1	+2	+3	+4	+5	+6	+7	+8	+9	-
+8	+2	+3	+4	+5	+36	+21	+8	+9	-821
8	4	9	16	25	216	147	64	81	3807
						1		1	2
						4	2		8
	1					1			2
2					1	1	1		4
3		1							4
2									2
			1						6
1									4
									13
									25
									14
									41
									64
									27
									22
									8
									7
									8
8	1	1	1	1	6	2	1	1	200

X'	Y'	f	f(X'
-9	-9	2	+14
-8	-8	1	+4
-8	-7	2	+11
-8	-6	2	+12
-7	-8	1	+4
-7	-7	1	+4
-6	-4	1	+2
-6	-5	3	+6
-6	-6	2	+7
-6	-7	1	+4
-5	-3	3	+6
-5	-4	3	+6
-5	-5	8	+12
-5	-6	2	+8
-4	0	2	0
-4	-1	4	+16
-4	-2	14	+112
-4	-3	38	+456
-4	-4	17	+272
-4	-5	12	+240
-4	-7	2	+56
-4	-8	2	+64
-3	0	16	0
-3	-1	19	+57
-3	-2	16	+80
-3	-3	17	+153
-3	-4	3	+36
-3	-5	1	+15
-2	-8	1	+16
-2	-7	1	+28
-2	-1	6	-24
-2	0	8	0
-2	-1	10	+16
-2	-2	11	+44
-2	-3	8	+72
-2	-4	3	+24
-2	-5	1	+10
-1	+1	1	-1
-1	0	8	-8
-1	0	1	0
-1	-1	1	+2
-1	-2	1	+2
0	+3	1	0
0	+2	3	0
0	+1	4	0
+1	+8	2	+10
+1	+4	2	+8
+1	+3	3	+9
+1	+1	1	+2
+2	+8	1	+12
+3	+4	1	+15
+4	+2	1	+8
+6	+5	1	+25
+6	+7	4	+168
+6	+6	1	+36
+6	+5	1	+30
+7	+8	1	+56
+7	+7	2	+98
+8	+6	1	+48
+9	+8	1	+72
	TOTAL		+3300

CORRELATION TABLE AND COMPUTATION OF VALUES FOR CURVE FITTI

X = DEGREES API

...D ...INTS	CLASS INTERVALS	f	d'	f(d')	f(d')²	2	4	6	8	10	12	14	16	18	20	22	24	26	28
						1.00	3.00	5.00	7.00	9.00	11.00	13.00	15.00	17.00	19.00	21.00	23.00	25.00	27.0
						2.99	4.99	6.99	8.99	10.99	12.99	14.99	16.99	18.99	20.99	22.99	24.99	26.99	28.9
						2	5	2	7	15	91	65	41	7	12	8	3	1	
						-9	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4
						-18	-40	-14	-42	-75	-364	-195	-82	-7	0	+8	+4	+9	+1
9500	19549-19450	2	+6	+12	144	162	320	98	252	525	1456	507	164	7	0	8	4	9	1
9400	19449-19350	5	+7	+35	245														
9300	19349-19250	3	+6	+18	108														
9200	19249-19150	3	+5	+15	75												1		
9100	19149-19050	4	+4	+16	64											2			
9000	19049-18950	9	+3	+27	81									1		3		1	
8900	18949-18850	4	+2	+8	16										3	2			
8800	18849-18750	15	+1	+15	15										8				
8700	18749-18650	15	0	0	0								5	5	4	1			
8600	18649-18550	55	-1	-55	55						2	15	8	1					
8500	18549-18450	89	-2	-78	156						4	10	10	1					
8400	18449-18350	67	-3	-201	603						14	15	11	1					
8300	18349-18250	27	-4	-108	432					3	38	17	6						
8200	18249-18150	22	-5	-110	550				1	5	17	3	3						
8100	18149-18050	8	-6	-48	288				5	5	12	1							
8000	18049-17950	6	-7	-42	294		1	1	2	2		1	1						
7900	17949-17850	6	-8	-48	384		2	1	1		2	1							
						2	2				2								
TALS		366	-	-870	3472	2	5	2	7	15	91	65	41	7	12	8	3	1	

TABLE - 2

CURVE FITTING

28	29	30	32	34	36	38	TOTALS
28.00	29.00	30.00	32.00	34.00	36.00	38.00	
28.99	29.99	30.99	33.99	34.99	36.99	38.99	
1	1	1	2	2	1	1	9
+5	+4	+3	+2	+1	0	-1	-
+5	+4	+3	+4	+1	0	-1	-21
5	16	21	216	147	84	21	2621
				1		1	2
			4	2			8
			1		1		2
		1	1				4
1							4
	1						8
							4
							18
							25
							24
							41
							84
							27
							22
							8
							7
							4
1	1	1	8	5	1	1	188

X'	Y'	f	f(X'Y')
-9	-9	2	+144
-8	-8	1	+48
-8	-7	2	+112
-8	-8	2	+128
-7	-6	1	+42
-7	-7	1	+49
-6	-4	1	+24
-6	-5	3	+90
-6	-6	2	+72
-6	-7	1	+42
-5	-3	3	+45
-5	-4	5	+80
-5	-5	5	+125
-5	-6	2	+60
-4	0	2	0
-4	-1	4	+16
-4	-2	14	+112
-4	-3	39	+432
-4	-4	17	+272
-4	-5	12	+240
-4	-7	2	+56
-4	-8	2	+64
-3	0	15	0
-3	-1	19	+57
-3	-2	15	+90
-3	-3	17	+153
-3	-4	3	+36
-3	-5	1	+15
-3	-6	1	+18
-3	-7	1	+21
-2	+1	6	-10
-2	0	8	0
-2	-1	10	+10
-2	-2	11	+44
-2	-3	8	+96
-2	-4	3	+24
-2	-5	1	+12
-1	+4	1	-4
-1	+3	3	-9
-1	0	1	0
-1	-1	1	+1
-1	-2	1	+2
0	+3	5	0
0	+2	5	0
0	+1	4	0
+1	+3	2	+10
+1	+4	2	+8
+1	+3	3	+9
+1	+1	1	+9
+2	+3	1	+12
+2	+4	1	+12
+2	+2	1	+8
+3	+3	1	+27
+3	+7	4	+168
+3	+4	1	+36
+3	+3	1	+30
+7	+3	1	+56
+7	+7	2	+98
+8	+3	1	+48
+8	+8	1	+72
		TOTAL	+3330

The computation formulas are:

$$\Sigma (Y') = Na + b \Sigma (X') \qquad (1)$$

$$\Sigma (X' Y') = a \Sigma (X') + b \Sigma (X')^2 \qquad (2)$$

where a and b are constants.

Substituting numerical values in (1) and (2)

$$-670 = 266a - 821b \qquad (3)$$

$$3360 = -821a + 3921b \qquad (4)$$

and solving (3) and (4) simultaneously for a and b,

$$a = 0.35605 \qquad b = 0.93151.$$

Substituting in straight line equations corresponding to (1)

$$Y' = 0.35605 + 0.93151 X'. \qquad (5)$$

Equation (5) is in arbitrary class interval units and must now be converted into original units. Since the class interval of Y' equals 100 BTU and the class interval of X' equals 2 API degrees:

$$Y' = \frac{Y''}{100} \qquad X' = \frac{X''}{2}$$

Substituting in (5) and simplifying,

$$Y'' = 35.605 + 46.576 X''. \qquad (6)$$

Equation (6) is now in BTU and API units, but must be transferred to the origin. Since the zero point for BTU was taken at 18,700 and for API degrees at 20,

$$Y'' = Y - 18{,}700 \qquad X'' = X - 20.$$

Substituting in (6) and simplifying,

$$Y = 17{,}804 + 46.6 X, \qquad (7)$$

which is the final equation relating BTU per pound of a fuel oil with its API gravity at 60 degrees F.

The coefficient of correlation is of importance because it measures the " relatedness " of the two variables and is given by

$$r^2 = \frac{a \Sigma (Y') + b \Sigma (X' Y') - NC^2}{\Sigma (Y')^2 - NC^2} \qquad (8)$$

where r is the coefficient of correlation and the other symbols retain their previous meaning and

$$C = \frac{\Sigma (Y')}{N}$$

Evaluating (8) and solving, $r = 0.823$.

The probable error of the coefficient of correlation is given by

$$P.E. = \frac{0.6745 (1 - r^2)}{N} \qquad (9)$$

Substituting, the probable error proves to be 0.011 and the complete coefficient of correlation is $r = 0.823 \pm 0.011$.

The standard error of estimate, s, is a measure of the scatter of the points around the line of central tendency and is given by

$$s^2 = \frac{\Sigma (Y')^2 - a \Sigma (Y') - b \Sigma (X' Y')}{N} \qquad (10)$$

Substituting in (10) and solving, $s = 1.4775$ in arbitrary units. In original units, $s = 1.4775 \times 100$ or 148 BTU.

Discussion of Results.

The plot of the oils used and the equation deduced therefrom are shown in Figure 1, where different symbols indicate different bunker grades. Figure 2 shows a comparison of the BTU-gravity formulas determined at the Naval Boiler Laboratory in 1933, 1935, and 1938:

1933..... $Y = 17687 + 57.9 X$

1935..... $Y = 17751 + 53.4 X$

1938..... $Y = 17804 + 46.6 X$.

The first two equations may be easily compared, since both were deduced from the same number of oils and of the same general character. The new formula, however, is influenced by factors absent in the derivation of the first two formulas.

The 1938 formula includes a much wider range of oils, straight run residua, blends from cracked and uncracked stocks, cracked residua, distillates and Diesel oils. Also, the cracked oils received were more deeply cracked than formerly.

nbols

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(9)

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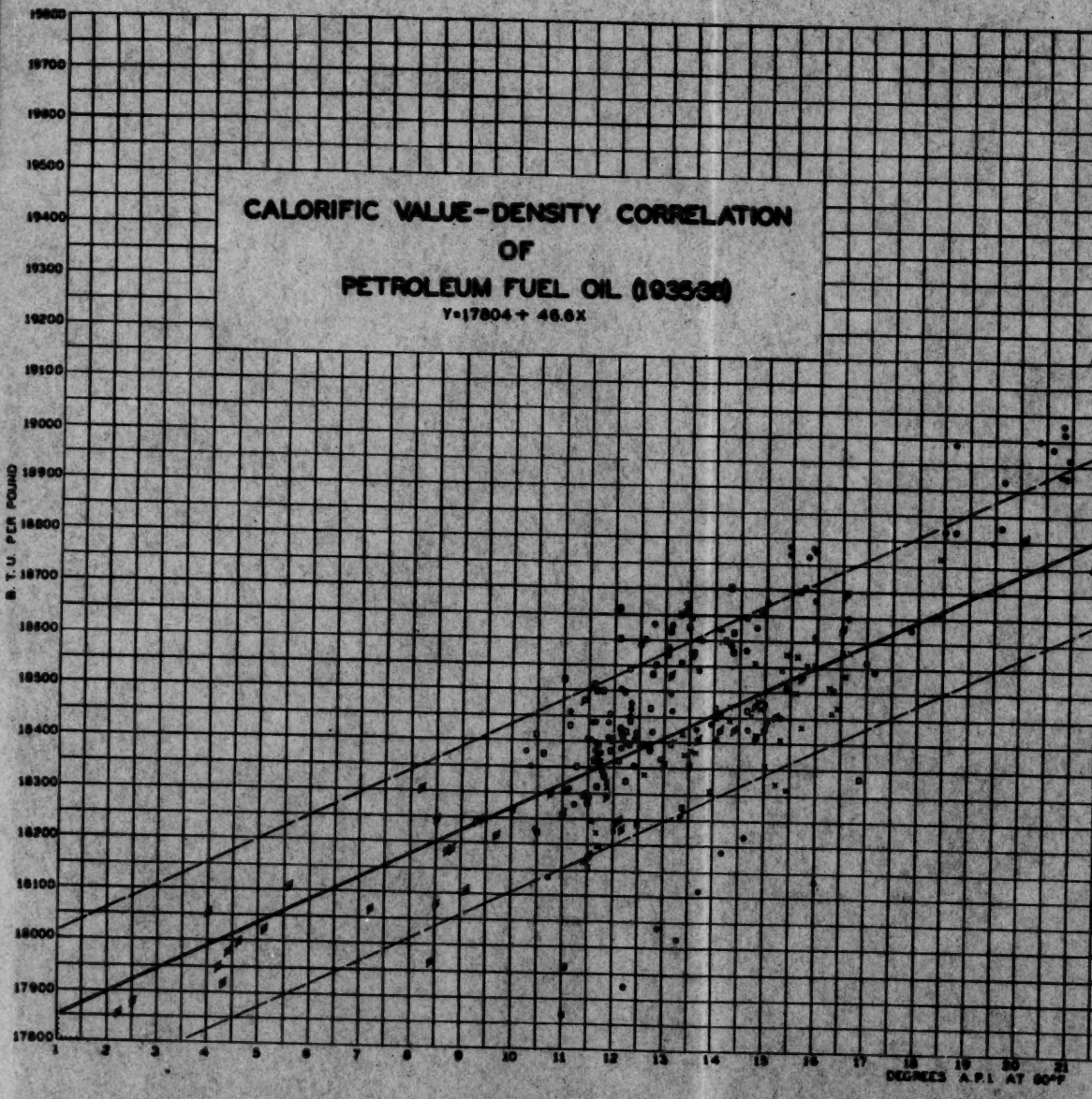
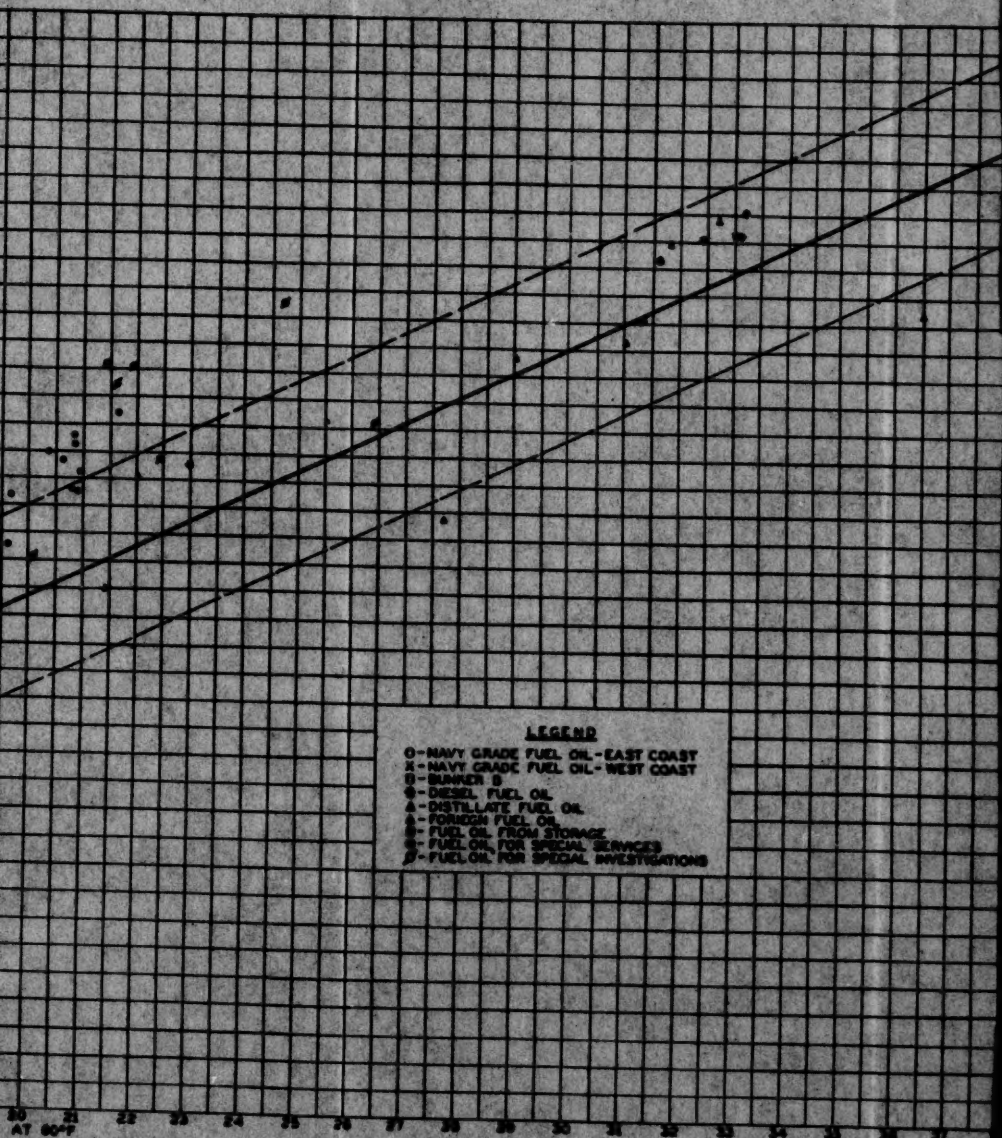

CALORIFIC VALUE-DENSITY CORRELATION
OF
PETROLEUM FUEL OIL (1935)
Y=17804+46.6X
B. T. U. PER POUND
DEGREES A.P.I. AT 60°F

FIGURE -


LEGEND
O - NAVY GRADE FUEL OIL - EAST COAST
X - NAVY GRADE FUEL OIL - WEST COAST
B - BUNKER B
D - DIESEL FUEL OIL
A - DISTILLATE FUEL OIL
F - FOREIGN FUEL OIL
S - FUEL OIL FROM STORAGE
S - FUEL OIL FOR SPECIAL SERVICES
S - FUEL OIL FOR SPECIAL INVESTIGATIONS
AT 60°F

URE -1

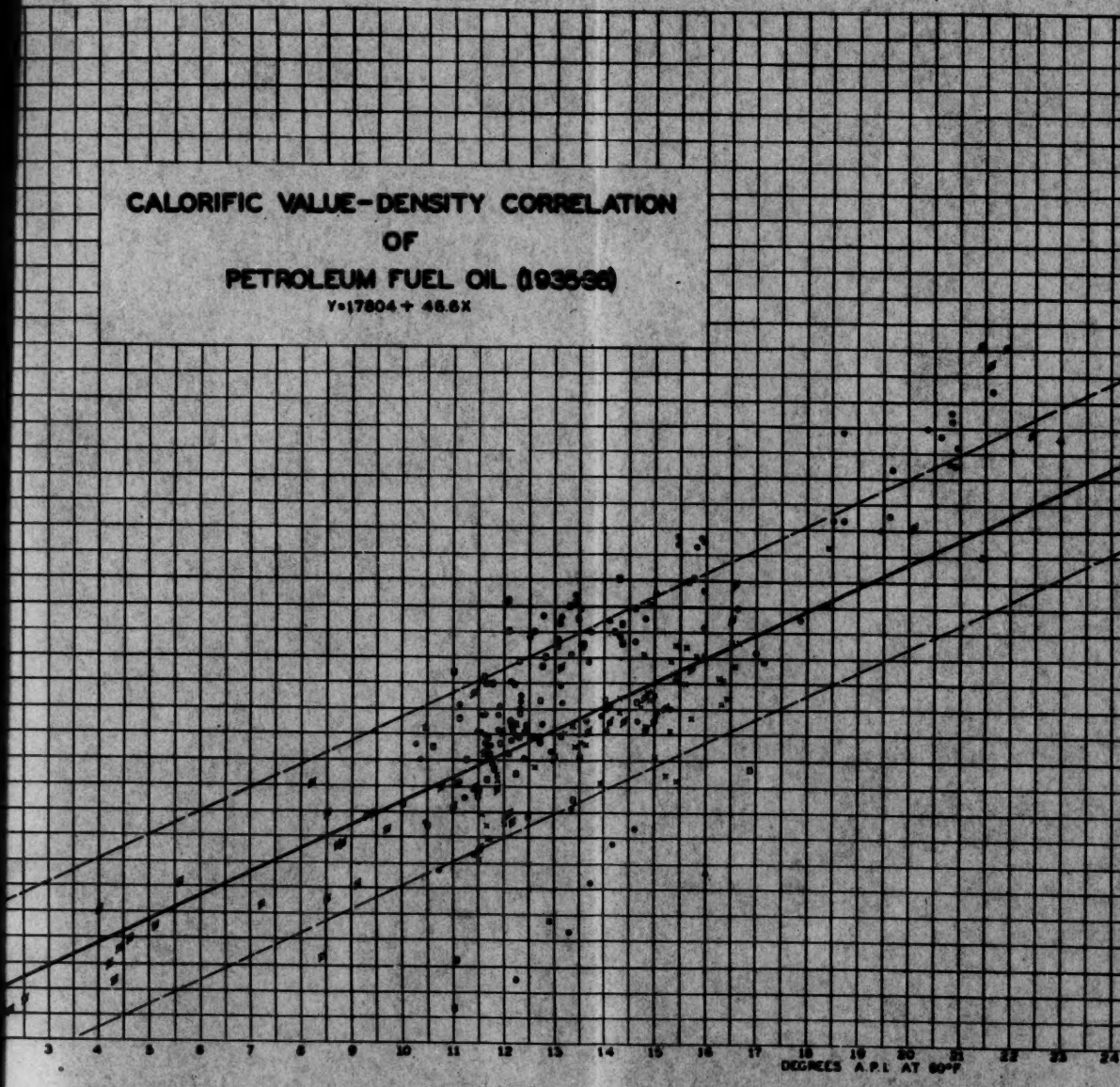
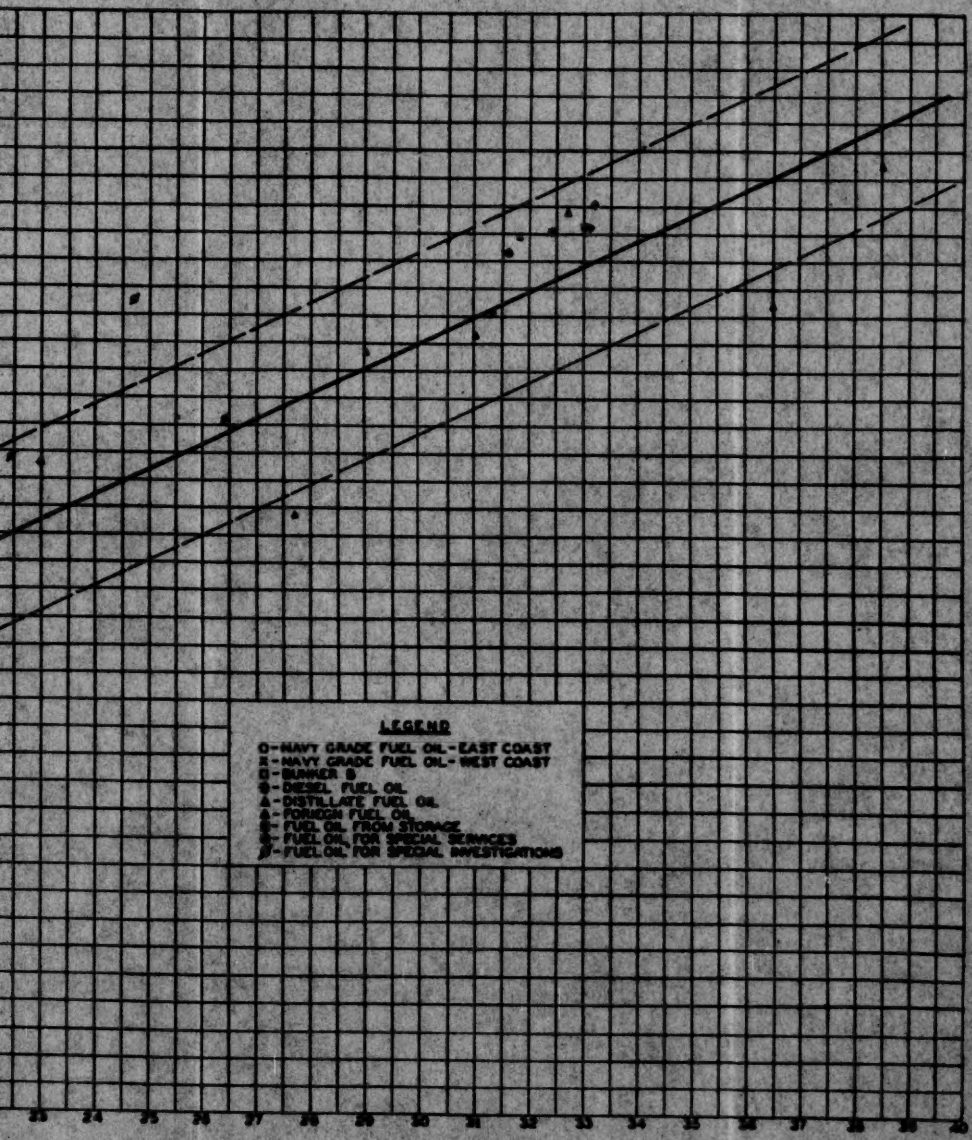

CALORIFIC VALUE-DENSITY CORRELATION
OF
PETROLEUM FUEL OIL (1953-58)
Y=17804 + 46.6X
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
DEGREES A.P.I. AT 60°F

FIGURE -1


LEGEND
O-NAVY GRADE FUEL OIL-EAST COAST
X-NAVY GRADE FUEL OIL-WEST COAST
□-BUNKER B
◇-DIESEL FUEL OIL
△-DISTILLATE FUEL OIL
▲-FOREIGN FUEL OIL
⊠-FUEL OIL FROM STORAGE
⊗-FUEL OIL FOR SPECIAL SERVICES
⊘-FUEL OIL FOR SPECIAL INVESTIGATIONS
23
24
25
26
27
28
29
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39
40

In Table 3, the calculated BTU values are shown for 10, 20, and 30 degrees API gravity fuel oils. For 10 degrees API, the values given by all three equations are approximately the same. For 20 degrees API, the BTU values decrease, with the 1938 value

TABLE 3.

YEAR	FORMULA	10° API	20° API	30° API	COEFFICIENT OF CORRELATION		STANDARD ERROR
1933	Y = 17687 + 57.9X	18,266	18,845	19,424	.912	.016	128 BTU
1935	Y = 17751 + 53.4X	18,285	18,819	19,353	.842	.028	114 BTU
1938	Y = 17804 + 46.6X	18,270	18,736	19,202	.823	.011	148 BTU

being the lowest. The variance at 30 degrees API is larger, but this variation is of minor importance, since these fuels fall outside the range of Navy-grade fuel oils.

It is apparent from Figure 2 that the slope of the equation has been decreasing and the Y-intercept increasing, with the 1938 formula having the smallest slope and the largest Y-intercept.

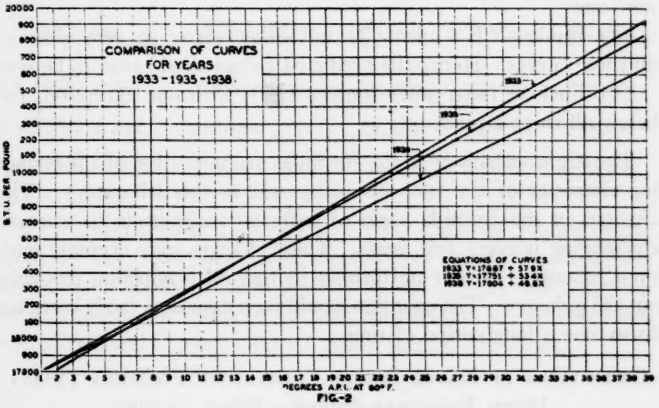


FIG.-2

The coefficient of correlation for the 1938 formula is smaller than the first two coefficients, but the correlation is considered valid. The decrease in coefficient is one-quarter of the previous decrease. The standard error of estimate is higher in the new

equation, indicating a greater variation in distribution ("scatter") around the line of central tendency represented by the equation, probably due to the greater variation with regard to the depth and manner of cracking.

Examination of Figures 1 and 2 shows that:

(a) Navy-grade fuel oils—West Coast (X) fall below or very close to the 1938 curve and, with two exceptions, entirely below the 1933 and 1935 curves. This means the values for the oils predicted by any of these formulas would tend to be high, the 1938 formula giving the most accurate relation.

(b) Navy-grade fuel oils—East Coast (°) are very evenly distributed with regard to all three curves.

(c) The distillate fuel oils (Δ) tend to increase the slope, with only one falling below the new curve.

(d) The fuel oils for special investigation (ϕ) show a very marked tendency to increase the slope and decrease the Y-intercept. The higher API values fall above and the lower ones below or near the new curve. For this reason, either of the older two equations would represent these particular oils better than does the new one.

(e) Bunker "B" oils (□) fall either above or very close to all three curves. Hence the predicted values would tend to be low.

(f) Fuel oil from other sources (■), with one exception, fall below all three curves.

The slight variations in the formulas are indicative of the changing character of the fuel oils being sent to this laboratory. The changes in the formula seem of sufficient magnitude to warrant challenging it every few years. These changes may decrease with time, assuming greater uniformity in fuel oil production throughout the industry. The equation would then assume a fairly constant form over a long period of time.

Comparison of Naval Boiler Laboratory Formula (1938) With Faragher-Morrell-Essex Curves.

Faragher, Morrell, and Essex,* of Universal Oil Products Company, determined separately the BTU-gravity relations for straight run fuel oils and for cracked residua. These curves are compared

* Universal Oil Products Booklet No. 86.

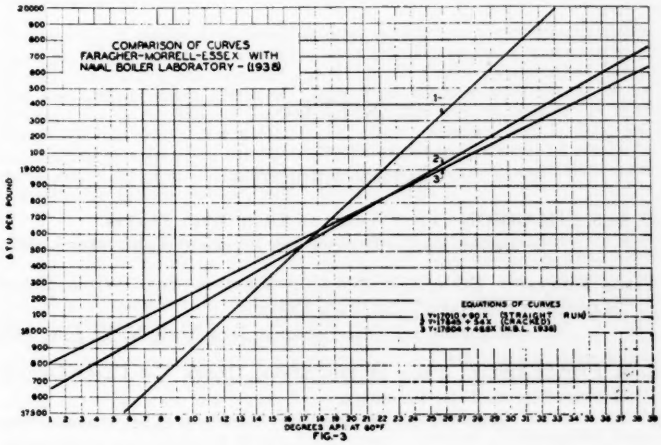

COMPARISON OF CURVES
FARAGHER-MORRELL-ESSEX WITH
NAVAL BOILER LABORATORY - (1938)
B.T.U. PER POUND
DEGREES API AT 60°F
EQUATIONS OF CURVES
1 Y=17010 + 90X STRAIGHT RUN
2 Y=17645 + 54X (CRACKED)
3 Y=17804 + 46.5X (N.B.L. 1938)

FIG.-3

TABLE 4.

FORMULA	FUEL OILS	10° API	20° API	30° API
Y = 17010 + 90X	Straight run	17,910	18, 810	19,710
Y = 17645 + 54X	Cracked	18,185	18,725	19,265
Y = 17804 + 46.5X	N.B.L. (1938)	18,270	18,736	19,202

with the Naval Boiler Laboratory (1938) curve in Figure 3 and Table 4. The latter curve approximates very closely the Faragher, Morrell, and Essex cracked fuel oil curve, thereby reflecting the use of greater quantities of cracked constituents in the manufacture of relatively recent Grade I Navy fuel oil deliveries.

NOTES.

INDEX TO NOTES.

U. S. S. CIMARRON: First American High Speed Tanker.
—Pacific Marine Review, San Francisco. Calif., March, 1939.

Cargo Motorship DONALD McKAY: First of the United States Maritime Commission's C-2 Type Vessels.
—Motorship and Diesel Boating, New York, N. Y., July, 1939.

S. S. CHALLENGE: First of the Steam Driven C-2 Class Demonstrates Record Fuel Economy.
—Pacific Marine Review, San Francisco, Calif., August, 1939.

U. S. S. NAVAJO: Ocean-Going Tug Launched at Mariners Harbor.
—The Nautical Gazette, New York, N. Y., August 26, 1939.

Principles Concerning the Main Propulsion Units of Warships.
—Zeitschrift des Vereines Deutscher Ingenieure, Berlin, Germany, July 15, 1939.

Miscellanea of Interest to Naval Engineers.

Inflammability of Gases.
—Refrigerating Engineering, New York, N. Y., September, 1939.

Diesel Engine Principle.
—Army and Navy Register, Washington, D. C., August 12, 1939.

New Meter for Measuring Shaft Horsepower.
—The Marine Engineer, London, England, July, 1939.

Relative Cost of Motorships and Steamships.
—The Log, San Francisco, Calif., August, 1939.

U. S. S. *CIMARRON:* FIRST AMERICAN HIGH SPEED TANKER.

The group of twelve high speed tankers which the *Cimarron* represents are of particular interest to the Navy as a valuable addition to the national defense. The Navy has acquired the U. S. S. *Cimarron* described below from the United States Maritime Commission together with the U. S. S. *Neosho*, built by the Federal Shipbuilding and Dry Dock Company. A third tanker will join this group, the U. S. S. *Platte*, launched July 8, 1939, and now nearing completion at the Sparrows Point, Maryland, plant of the Bethlehem Steel Company. The article is reprinted from the March, 1939, issue of the Pacific Marine Review, San Francisco, Calif.

The *Cimarron*, first of the group of twelve National-Defense features tankers, was launched at the plant of the Sun Shipbuilding & Dry Dock Company, Chester, Pa., on Saturday, January 7. She was sponsored by Mrs. Wm. D. Leahy, wife of Admiral Wm. D. Leahy, Chief of Naval Operations, United States Navy. The christening took place in the presence of several thousand people, including Government and company officials. The launching was successful in every respect and the *Cimarron* was immediately towed to the yard's fitting-out dock, where she was made ready for her official sea trials over the Naval Trial Course off Rockland, Maine. These successfully completed, she was taken over by the United States Maritime Commission and delivered to the U. S. Navy Yard at Philadelphia, Pennsylvania, February 6.

The vessel is of the single continuous freeboard deck (with poop, bridge, and forecastle erections), twin longitudinal bulkheaded, type of bulk oil carrier with propelling machinery located at the after end. Special attention has been paid to fireproof construction and equipment; the accommodations for officers and crew are ample and modern; and all up-to-date navigating equipment has been provided.

The ship is fitted with two all-steel masts and two steel Samson posts, the foremast equipped with a five-ton capacity steel cargo boom on the forward side of the mast and each of the Samson posts equipped with two steel hose-handling booms, a two-ton capacity boom on the after side and a four-ton capacity boom on the forward side, and provisions for the installation of a 40-ton boom.

The particulars of the vessel are as follows:

Length overall, feet and inches	553—0
Length between perpendiculars, feet	525
Breadth molded, feet	75
Deadweight on 30-foot draft, tons	16,735
Deadweight on 31-foot, 7⅝ inches, summer freeboard draft, tons	18,230
Cargo capacity, barrels	147,150
Trial speed, knots	18
Total complement accommodated	69

The *Cimarron* is propelled by Westinghouse turbines developing a normal shaft horsepower of 6750 per shaft on two shafts, the shaft RPM to be 96 at this 6750 SHP. Steam is supplied by four Babcock & Wilcox sectional header watertube boilers designed for working steam pressure at the superheater outlet of 450 pounds per square inch and a total temperature of about 750 degrees F. Each boiler is fitted with Todd oil burners.

The engines on each shaft consist of one high pressure ahead and one low pressure ahead turbine arranged in separate casings with an astern turbine in the low pressure ahead casing. There are two main condensers and one

auxiliary condenser. The machinery equipment also includes two 400 Kw 230 volt, 3 phase, alternating current geared turbo-generator sets. The vessel has two cargo oil pump rooms—one aft being provided with centrifugal main cargo pumps—actuated by motors located in the turbine machinery space, and a steam actuated vertical reciprocating stripper pump, and a midship pump room provided with steam actuated vertical reciprocating main cargo oil and stripping pumps.

HULL FEATURES.

A cruiser stern and a bulbous bow are noticeable features of the hull design.

The bow carries fittings for a paravane.

Extensive welding was used in bulkheads, bottom and side shells, and in deck houses.

All features for safety of navigation, safety of working conditions, and safety against fire menace that have been approved through the long experience of the Standard Oil Company of New Jersey are incorporated in the construction and the equipment of this tanker and her 11 sisters.

American Marine Paint Company's "Germicide" anti-corrosive, anti-fouling, and boot-topping were used as shell coatings on this hull for speed and protection.

POWER PLANT.

As indicated above, the propulsion plant consists of two Westinghouse double reduction geared cross compound turbine units. These units are of the most modern design, into which Westinghouse has built the best results of over 30 years' experience in the design and construction of marine geared turbines.

Each unit comprises one high pressure and one low pressure turbine of the combined impulse and reaction type arranged for cross-connection operation. Each unit actuates its line and propeller shafting through Westinghouse double reduction gearing enclosed in a single case.

Each unit is designed to develop its normal output of 6750 shaft horsepower (when supplied with steam at 425 pounds per square inch gage pressure and 725 degrees F. total temperature, and when exhausting into a vacuum of 28½ inches) at a propeller shaft speed of 96 RPM.

For reversing, a two stage impulse type "astern" turbine is incorporated in the exhaust end of each "ahead" low pressure turbine.

Propeller thrust is absorbed through a Kingsbury type thrust bearing mounted in the forward end of the gear casing on the low speed gear shaft of each unit.

Three nozzle groups distribute steam to each unit turbine. These are arranged with hand operated nozzle control valves for overload and for reduced power operation, in addition to the main control of the primary nozzle group.

Cross connection piping between the high and low pressure turbines in each unit is arranged to permit either the high or the low pressure turbine to be operated singly for driving the propeller shafting in emergency "ahead" operation.

THE CONDENSERS.

Each low pressure turbine casing is mounted on top of and exhausts directly into an athwartship surface condenser of the two pass radial flow type with 6500 square feet of cooling surface. Each condenser has a capacity for condensing 52,000 pounds of steam an hour under a maintained

vacuum of 28 inches Hg. and when supplied with cooling sea water of 80 degrees F. temperature at the rate of 10,500 gallons per minute. Westinghouse twin element two-stage air ejectors fitted with intermediate and after condensers of the surface type serve each condenser.

REDUCTION GEAR CONDITIONS.

At normal full power operation, that is, with each turbine of each unit developing 3375 shaft horsepower and the propeller shaft turning at 96 revolutions per minute, the high speed pinion of the high pressure turbine turns at 5855 RPM, the high speed pinion of the low pressure turbine at 4725 RPM, and the low speed pinion at 527 RPM. The high speed pinions and high speed gear wheel have pitch circle diameters of 8.075 inches, 10.006 inches, and 89.71 inches, respectively. For the low speed pinion and wheel the respective pitch circle diameters are 20.064 inches and 111.80 inches. Under these conditions of power and speed the ratio (tooth pressure per inch of face divided by pitch circle diameter in inches) for each of these pinions is: high pressure high speed, 67.8; low pressure high speed, 54.7; and low speed, 56. This rating is considered conservative for continuous service.

FEED PUMPS.

One of the most important units of the marine power plant, and increasingly so as the steam pressures rise, is the feed pump which returns the condensate and supplies make-up feed water to the boilers. On the *Cimarron* and on all her 11 sisters this function is entrusted to a pair of De Laval turbine drive centrifugal pumps, each of which is capable of taking care of the boiler requirements at full load. The pumps are three stage and are directly connected to the turbine, which drives them at 4000 RPM. The pumps have 4-inch diameter suction openings and 3-inch diameter discharge. At normal speed each pump will deliver 300 gallons of water per minute against a discharge pressure of 575 pounds per square inch gage with the water at a temperature of 235 degrees F. The impellers of these pumps and all internal parts are of acid resisting bronze.

The steam generating plant on the *Cimarron* consists of four boilers of the Babcock and Wilcox single pass sectional header marine type equipped with water cooled furnace and designed for high combustion efficiency, low maintenance costs, and savings in space and weight. These boilers have built in superheaters and combustion air heaters. Combustion air passes through the heaters in the uptake down the back of furnace between furnace wall and casing, across the bottom of furnace and up to the burners. There are no baffles either in the banks of boiler tubes or in the air pre-heater tubes.

DESIGNED PERFORMANCE.

The design of the turbines called for a guaranteed performance to give the following results:

When the turbines are operating "ahead" non-bleeding and supplied with steam at 425 pounds (gage) throttle pressure, 725 degrees F. total temperature and 28½-inch vacuum at the turbine exhaust, the steam rate per shaft horsepower hour is under 7.1 pounds.

The propulsive power plant and boiler installation are designed to afford a fuel consumption of less than 0.60 pounds (of 12 degrees API—85 seconds Saybolt U. Viscosity fuel oil) when the plant is operating at normal sea service power.

DECK MACHINERY.

Deck auxiliaries for the *Cimarron* were supplied by the American Engineering Company and include steering gear, winches, and windlass. The steering gear is of the electro hydraulic quadrant type arranged to be controlled by manually operated wheel or by gyro pilot. The winches and windlass are steam engine operated.

NAVIGATION EQUIPMENT.

The navigation and communication equipment includes: complete radio equipment and radio auto alarm; a radio direction finder; a 24-inch Navy standard searchlight; a Submarine Signal Company Fathometer; and Sperry gyro pilot, Sperry master gyro compass and repeaters, and Sperry Course Recorder.

A Carrier Corporation refrigerating plant will take care of the steward's perishable stores. This plant is of the direct expansion Freon type with full automatic control. It is designed for economic, dependable operation with a minimum of control.

TRIAL TESTS.

Cimarron on January 24 left the Sun yard at Chester loaded with a large party of technical experts representing the U. S. Navy, the U. S. Maritime Commission, the Standard Oil Company of New Jersey, the Sun Shipbuilding and Dry Dock Company, the Westinghouse Electric and Manufacturing Company, the Babcock and Wilcox Company and all the parties concerned in the equipment and machinery under test.

She proceeded to Rockland, Maine, where on January 25, 26 and 27 she was subjected to a very gruelling Navy Standard Trial for speed, economy, and maneuverability.

In speed she easily exceeded 18 knots, making that speed at a propeller speed of 92.5 RPM.

In economy her normal full power run results show a fuel consumption of less than 0.6 pound per shaft horsepower hour.

In reverse she develops 78 per cent of her full ahead power. In maneuvering she proved herself very handy, turning in comparatively small circles and stopping from full speed in remarkably short time.

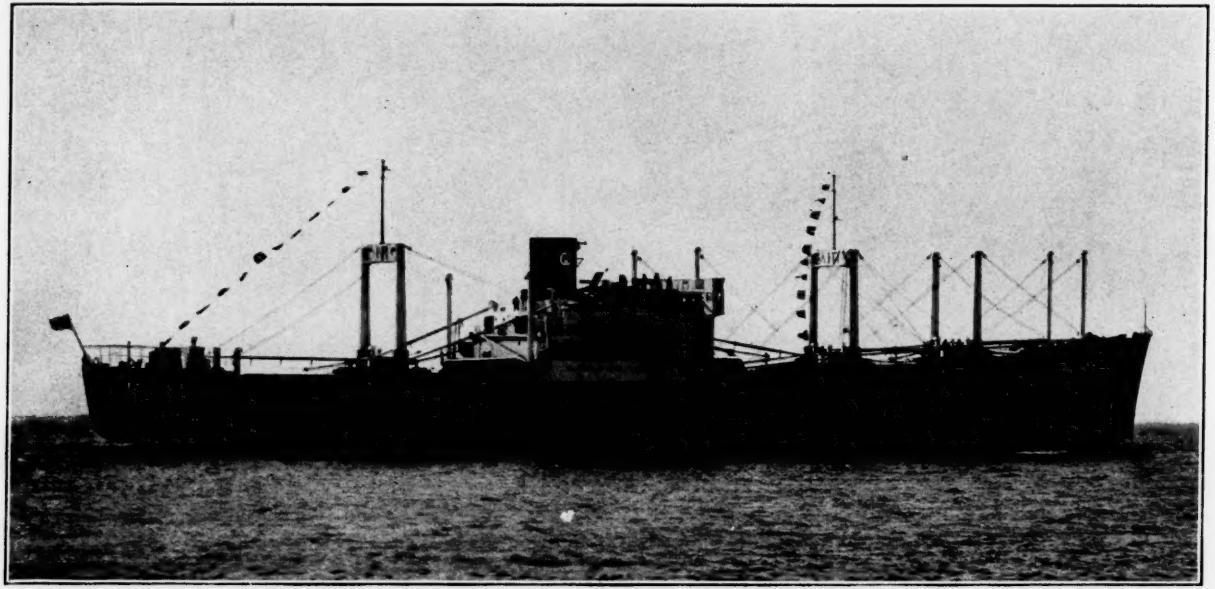
All hands were agreed that the lines of the *Cimarron* have produced a very seaworthy hull with a very comfortable, easy motion in a sea way.

This group of twelve ships is being constructed under the terms of an agreement entered into by the Standard Oil Company of New Jersey with the U. S. Maritime Commission on January 3, 1938. According to the provisions of the agreement the Government's defense-feature expenditure for the building of these vessels amounts to a total of $10,563,000 and the company's share of the expense will total $26,993,004. No "subsidy" is involved. Four shipyards, namely, Bethlehem Steel Company, Shipbuilding Division (Sparrows Point); Federal Shipbuilding and Dry Dock Company; Newport News Shipbuilding and Dry Dock Company; and the Sun Shipbuilding & Dry Dock Company; will each build three of the ships.

The three vessels at Sun will be identical to the *Cimarron*.

The three building at Federal differ in that they will be propelled by General Electric geared turbines.

The three building at the Bethlehem yard will be propelled by Bethlehem-Parsons turbines operating through De Laval gears and taking steam from Foster Wheeler boilers.



Photograph by Courtesy of the United States Maritime Commission.

M. V. Donald McKay, Cargo Motorship, C-2 Type.

The three building at Newport News will have Newport News-Parsons turbines, De Laval gears, and Foster Wheeler boilers.

The main reduction gears for the six tankers being built by Bethlehem and Newport News will be of the double helical, double reduction type, designed and manufactured according to the usual De Laval standards. The high pressure pinion will run normally at 5494 RPM and the low pressure pinion at 2714 RPM for 95 RPM of the propeller. Each of these pinions will mesh with a first reduction wheel, which is to be mounted on a solid shaft extending through the corresponding hollow second reduction pinion and connected to the latter by another flexible coupling of the claw type. The two second reduction pinions mesh with one large gear wheel mounted on the main gear wheel shaft by forced fit and screwed keys. The main gear wheel shaft also carries the thrust collar for the Kingsbury type main propeller thrust bearing, which is arranged at the forward end of the gear case. This large gear wheel is approximately 128 inches in diameter and its designed normal speed is 95 propeller RPM when transmitting 6750 SHP.

CARGO MOTORSHIP *DONALD McKAY:* FIRST OF THE UNITED STATES MARITIME COMMISSION'S C-2 TYPE VESSELS.

The *Donald McKay* and her five sister ships, *Mormacuren, Mormachawk, Mormacdove, Mormacgull,* and *Mormaclark,* will be operated by the Moore and McCormack Lines. The abstract is from "Motorship and Diesel Boating," published July 1939 by Diesel Puplications, Inc., New York, N. Y.

Although the characteristically expeditious and nonchalant manner in which the trials were carried out by the Sun Shipbuilding Co. gave no indication of the fact, the acceptance tests of the motorship *Donald McKay,* on June 6 and 7 last, marked the completion of the first of a group of ships that may have a profound influence on the American merchant marine. This group comprises 18 Diesel powered ships of three different types, being built for the U. S. Maritime Commission for operation by private owners.

These 18 ships represent the beginning of the first large scale and long range motorship building program ever undertaken in the United States, and since they incorporate several different variations of Diesel propulsion that will operate in conjunction with an equal number of steam turbine installations in the same type of ships, very valuable comparative operating data will become available for guidance in future construction.

The *Donald McKay* is the first of six cargo ships of the C-2 type contracted for with the Sun Shipbuilding and Dry Dock Co., of Chester, Pa., and is equipped with Sun-Doxford Diesels, direct connected to the propeller. The general features of design were described in our July, 1938, and April, 1939, issues. Since then some changes in structural arrangement have been made to suit the requirements of the United States-Baltic ports trade in which the Moore & McCormack Lines will operate the ships under a contract arrangement.

One of the principal changes was the addition of another deck in the deckhouse to provide accommodations for 12 passengers. Another was the addition of refrigerated cargo space around the hatch openings on the second deck, and equipment for handling liquid cargo. Six of these spaces are arranged for frozen cargo but four of them are also suitable for handling pre-cooled hot fruit and vegetables. A seventh compartment is arranged for transporting apples, at a temperature of 35 degrees. This made it necessary to increase

the size of the auxiliary plant by adding refrigerating machines and cargo pumps. To handle the extra load a third Diesel-generator set of 230 Kw. capacity was installed.

The general characteristics of the *Donald McKay* are as follows:

Length, overall, feet and inches	459–0
Length, between perpendiculars, feet and inches	435–0
Breadth, molded, feet and inches	63–0
Depth at side, molded, feet and inches	40–6
Load draft, feet and inches	29–9
Displacement, full load, tons	13,900
Cargo deadweight, tons	7,500
Gross tonnage, tons	8,228
Sea speed, loaded, knots	15½
Total power, BHP	6,000
Propeller speed, RPM	92
Propeller diameter, feet	19
Fuel capacity, tons	1,501
Cargo capacity, tons	7,618

The vessel is of the shelter deck type, with second complete deck below the shelter deck. A third deck extends forward and aft from the machinery compartment. There are five cargo holds, three forward of the machinery space and two aft. Eight watertight subdivisions are provided by seven bulkheads of which the forward and aft ones are carried watertight to the shelter deck and the remainder to the second deck. Deep tanks are provided fore and aft, extending to the third deck, for carrying oil or ballast when light, and for storage of ordinary cargoes. These deep tanks are provided with hinged hatches, with oil-tight gaskets. Double bottoms extend from forward collision bulkhead to frame 160, practically the full length of the ship.

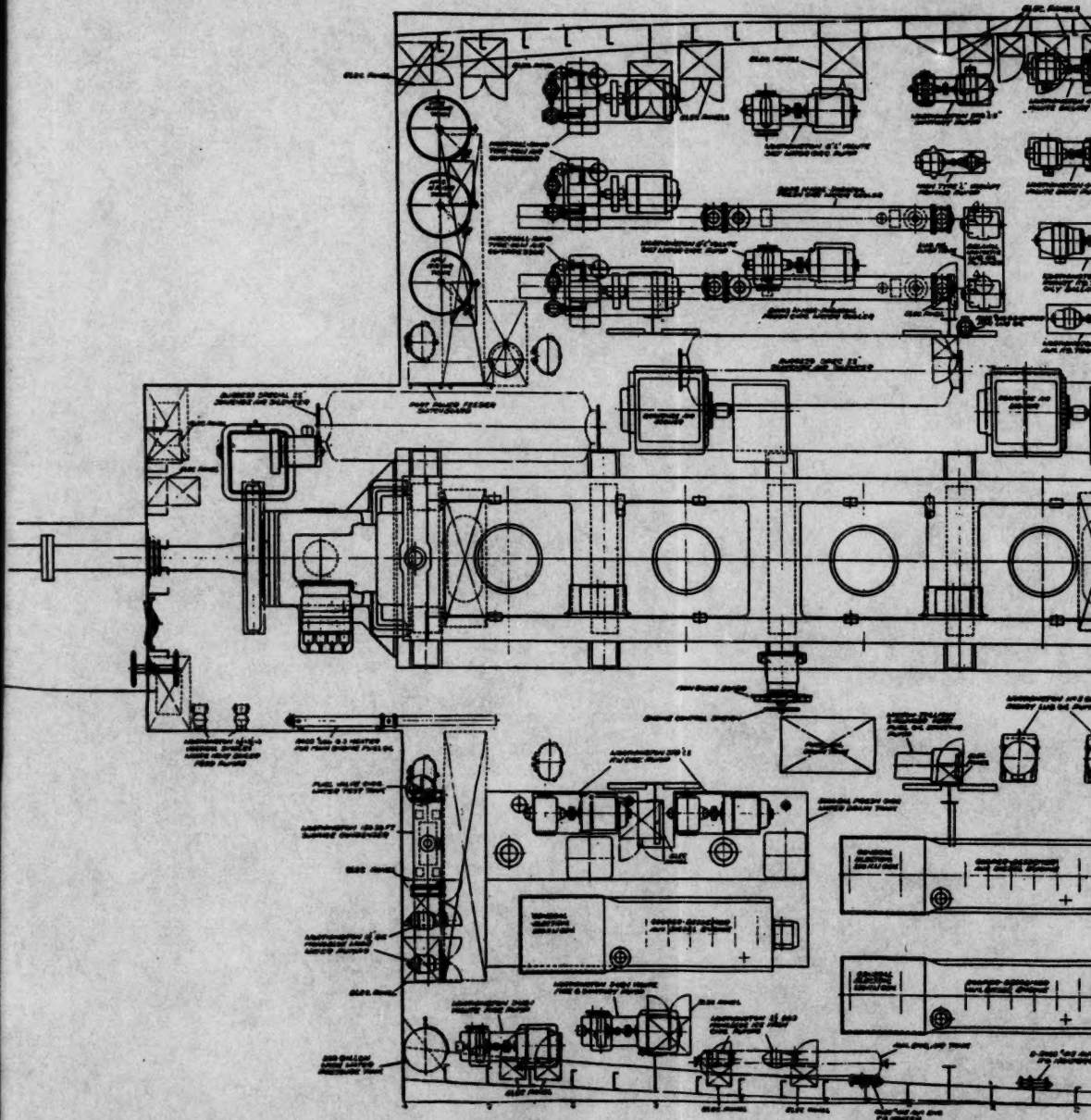
All living quarters are concentrated in a single deck structure between No. 3 and No. 4 hatches, directly over the engine room. At shelter deck level are the crew's quarters, including a messroom and toilet and shower facilities for both deck and engine room crew. On this deck also is the galley, equipped throughout with the most modern electric cooking devices, with a dumbwaiter connecting with the service pantry adjacent to the dining saloon above.

On the boat are the quarters for officers, and above this is the passenger deck, with the lounge and dining saloon occupying the central forward part of the house and three passenger staterooms outboard on each side with accommodations for two passengers each.

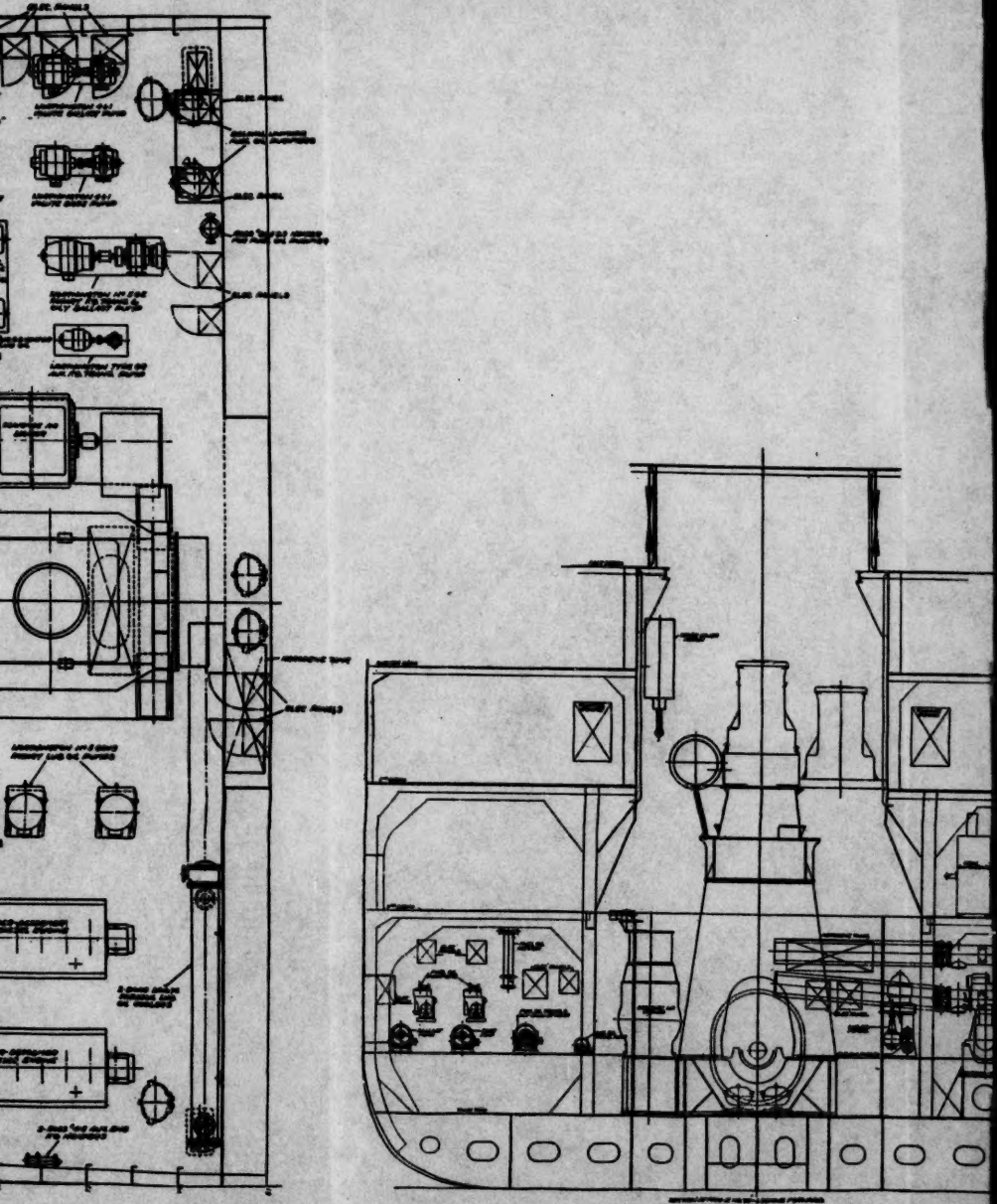
On the navigating deck are the captain's cabin, captain's office, captain's staterooms, wheelhouse, chart room, gyro room. Running hot and cold fresh water are provided throughout.

The pilot house is completely equipped with the most modern navigational instruments, including a Sperry gyro-compass and metal mike, Fathometer for sounding, R.C.A. direction finder, and a smoke indicator to detect fire in any compartment in the ship. Sound apparatus includes both an air horn and a steam whistle, with operating levers under the central forward window.

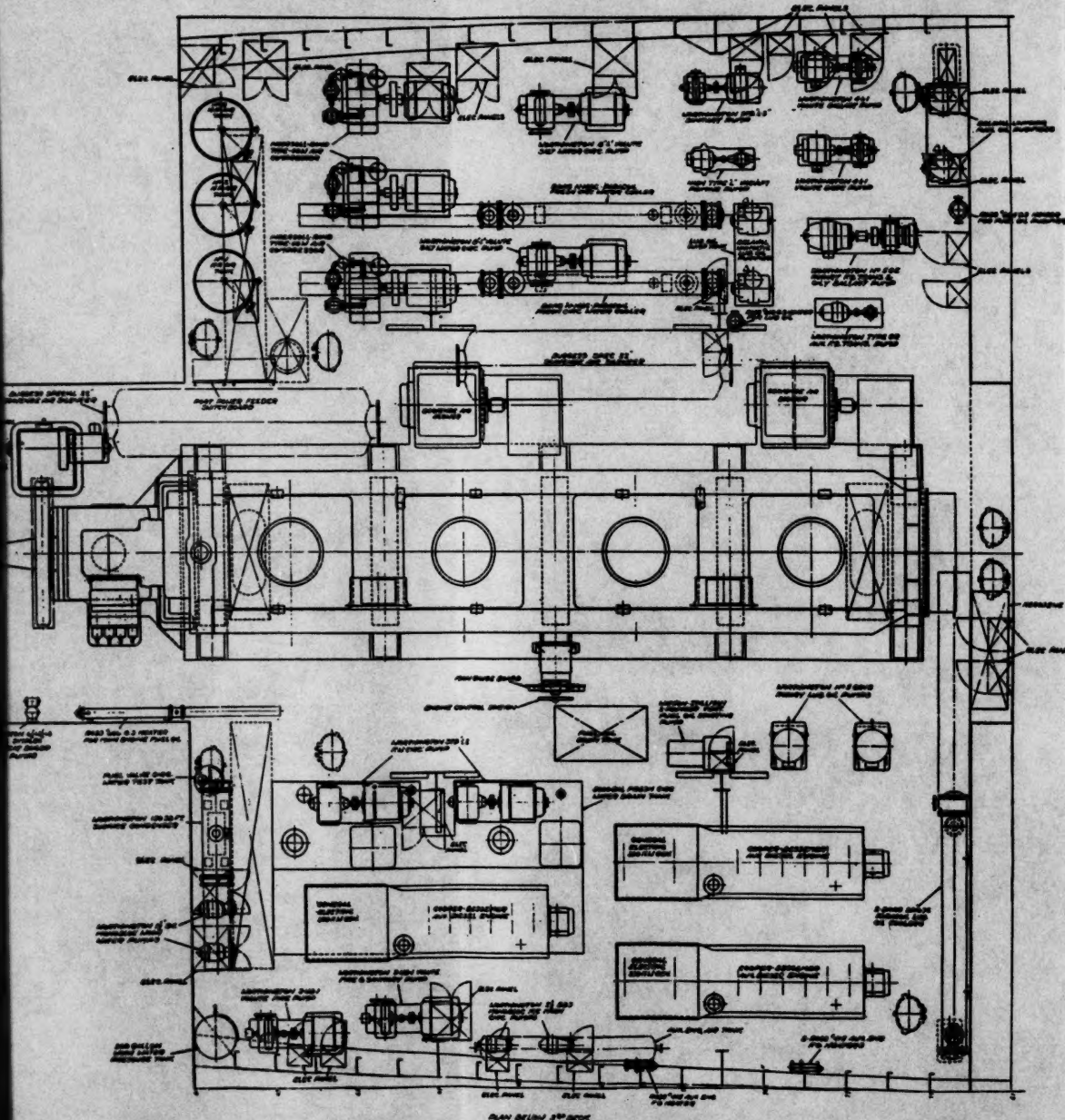
For handling cargo there are eight kingposts which support five-ton cargo booms and also serve as ventilators for the holds. At the forward end of No. 3 and after end of No. 4 hatches, there are two 30-ton booms. To serve the booms there are 12 electrically operated American Engineering cargo winches, each with a capacity of three tons at about 220 feet per minute. The anchor windlass and the warping capstan, of American Engineering make, are also electrically driven. The AECO stearing gear is of the electro-hydraulic type with telemotor control from the pilot house.



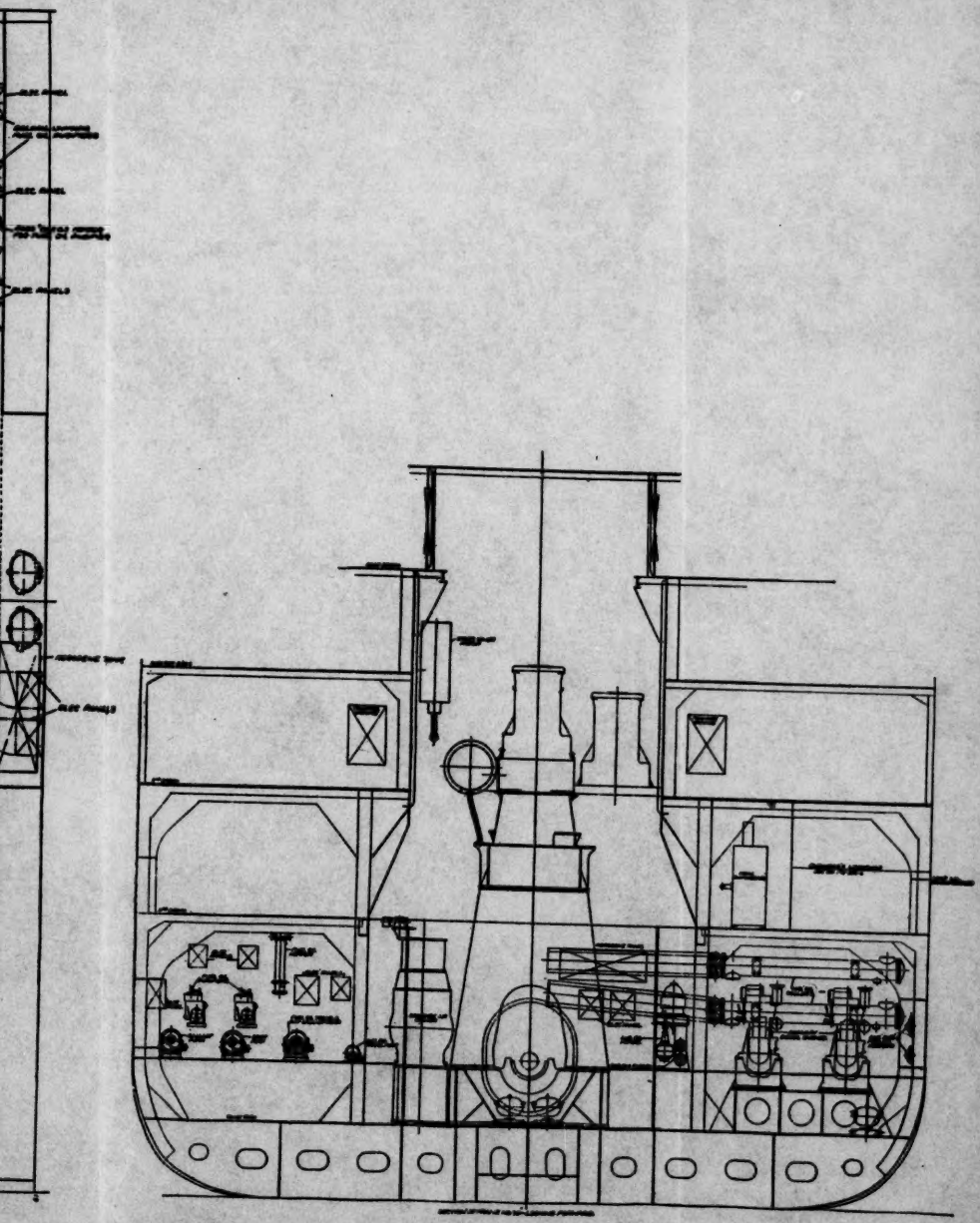
THESE PLAN VIEWS OF ENGINE ROOM AT FLOOR LEVEL AND AT THIRD DECK LEVEL, AND THE SECT



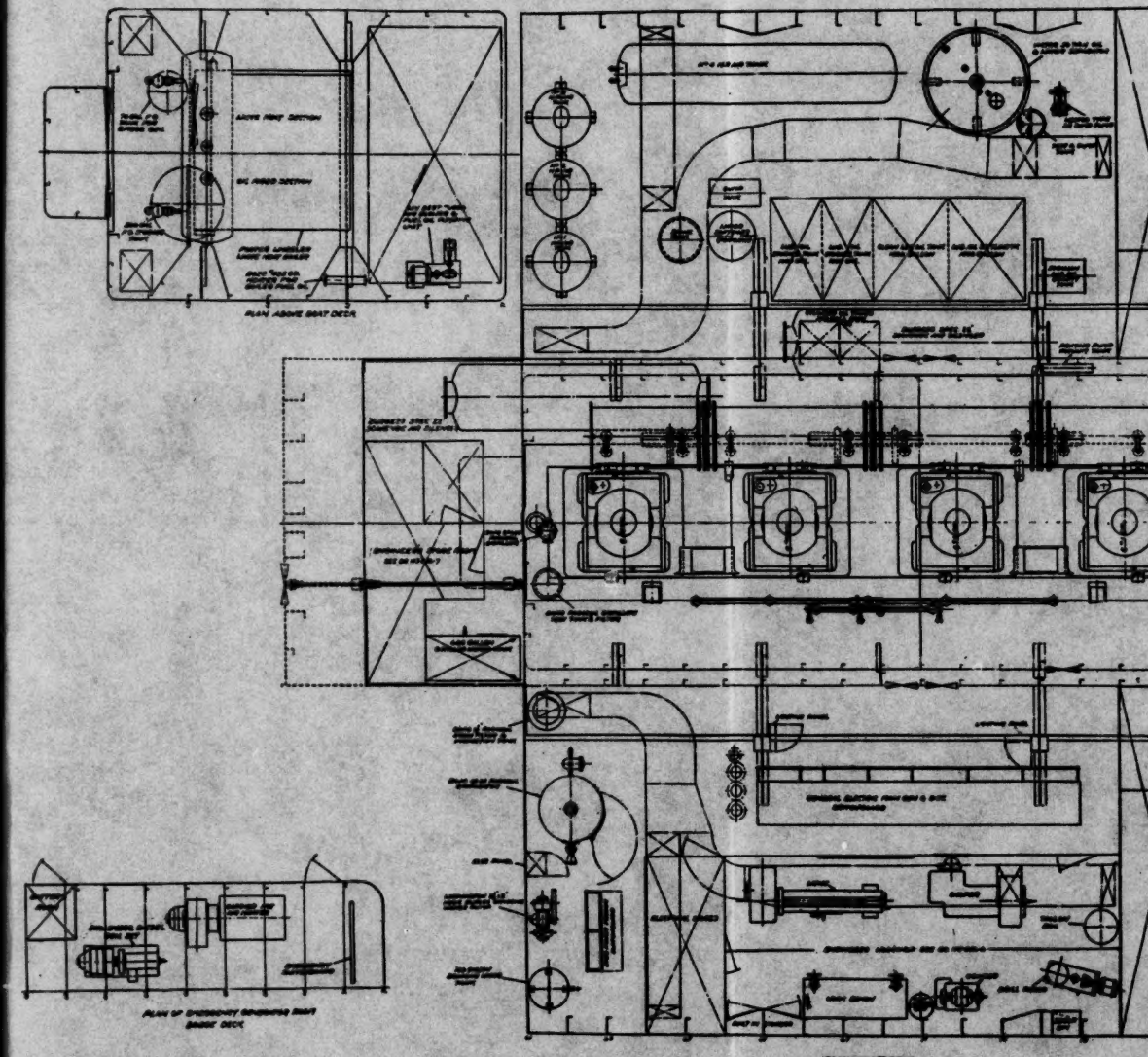
ND THE SECTIONAL VIEWS, SHOW THE COMPLETE MACHINERY ARRANGEMENT OF THE "DONALD McKAY."



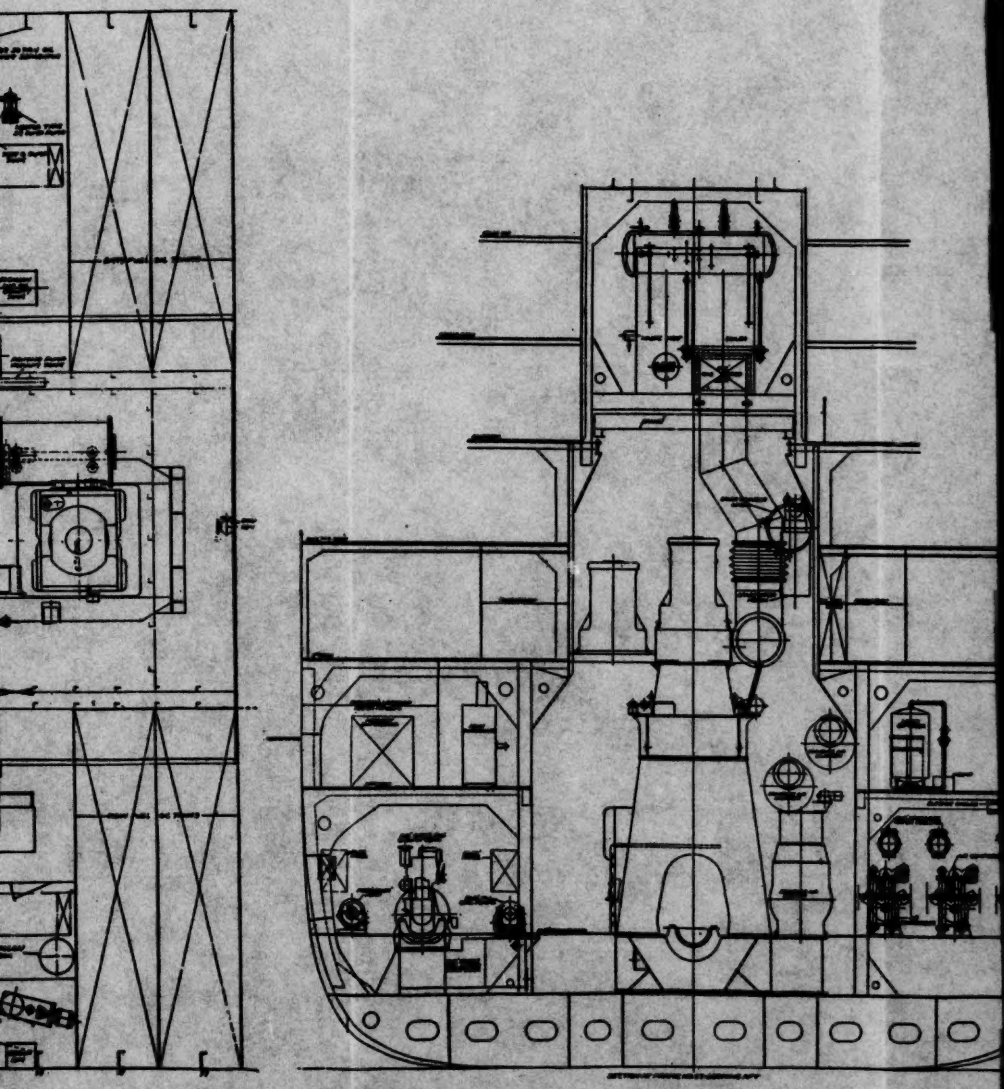
THESE PLAN VIEWS OF ENGINE ROOM AT FLOOR LEVEL AND AT THIRD DECK LEVEL, AND THE SECTIONAL VIEWS, SHOW THE



SHOW THE COMPLETE MACHINERY ARRANGEMENT OF THE "DONALD McKAY."



THESE PLAN VIEWS OF ENGINE ROOM AT FLOOR LEVEL AND AT THIRD DECK LEVEL, AND THE SECTIONA



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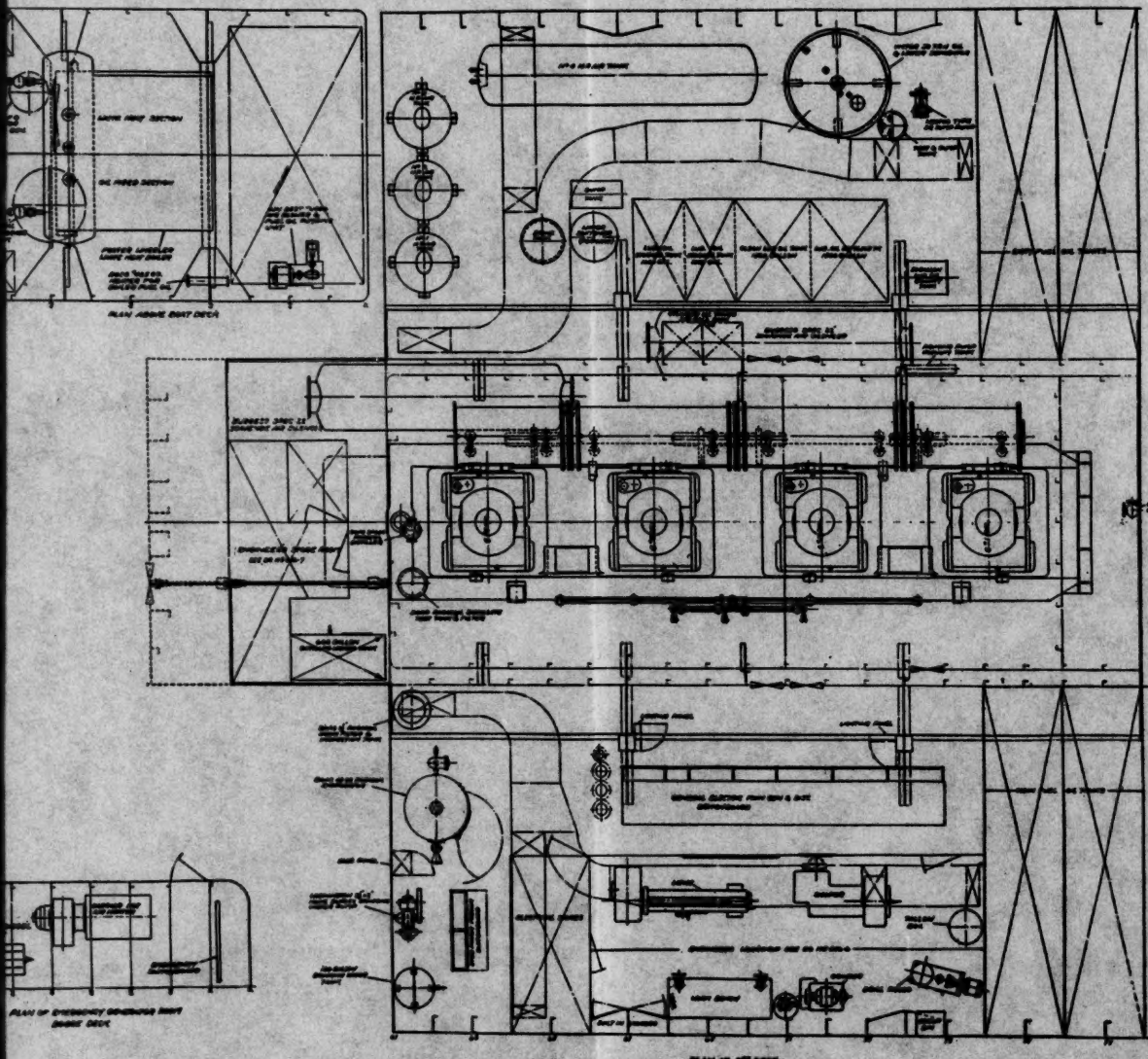

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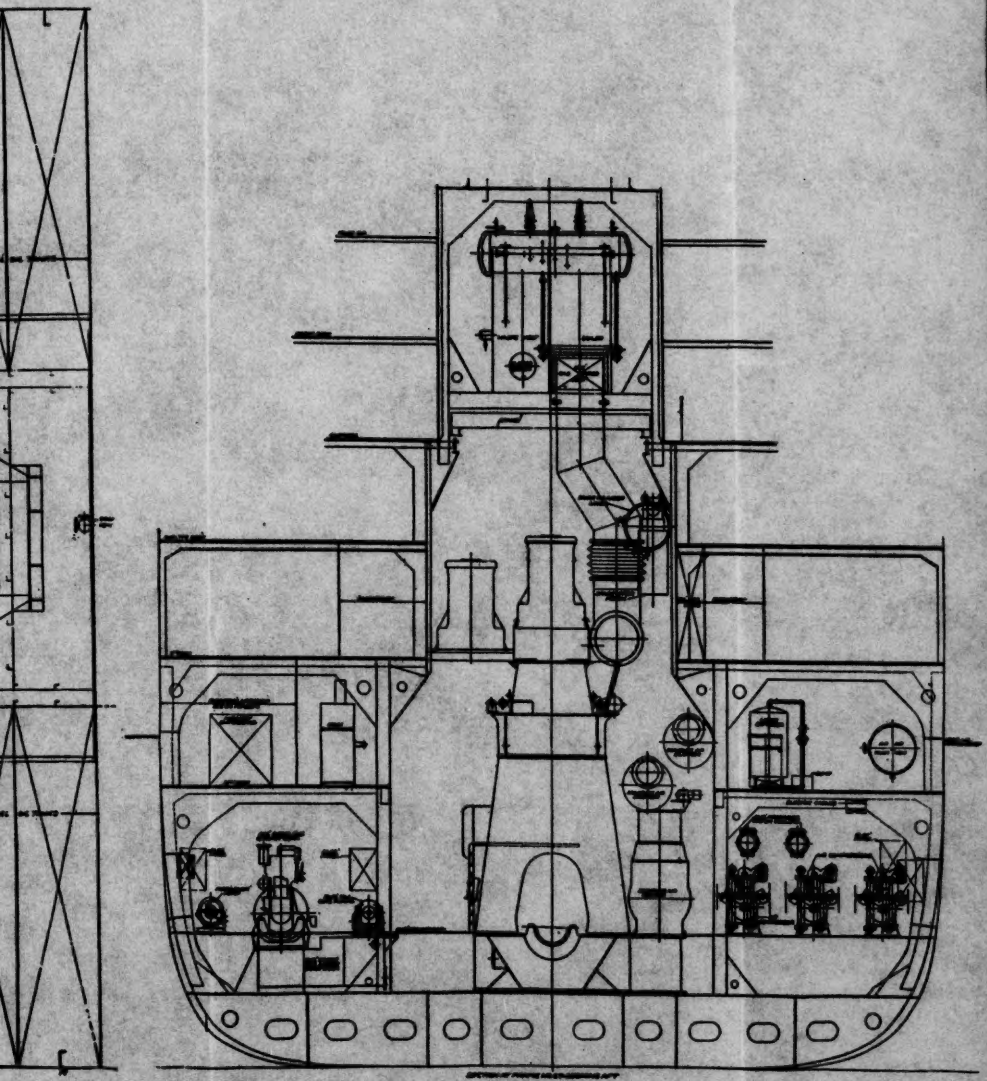

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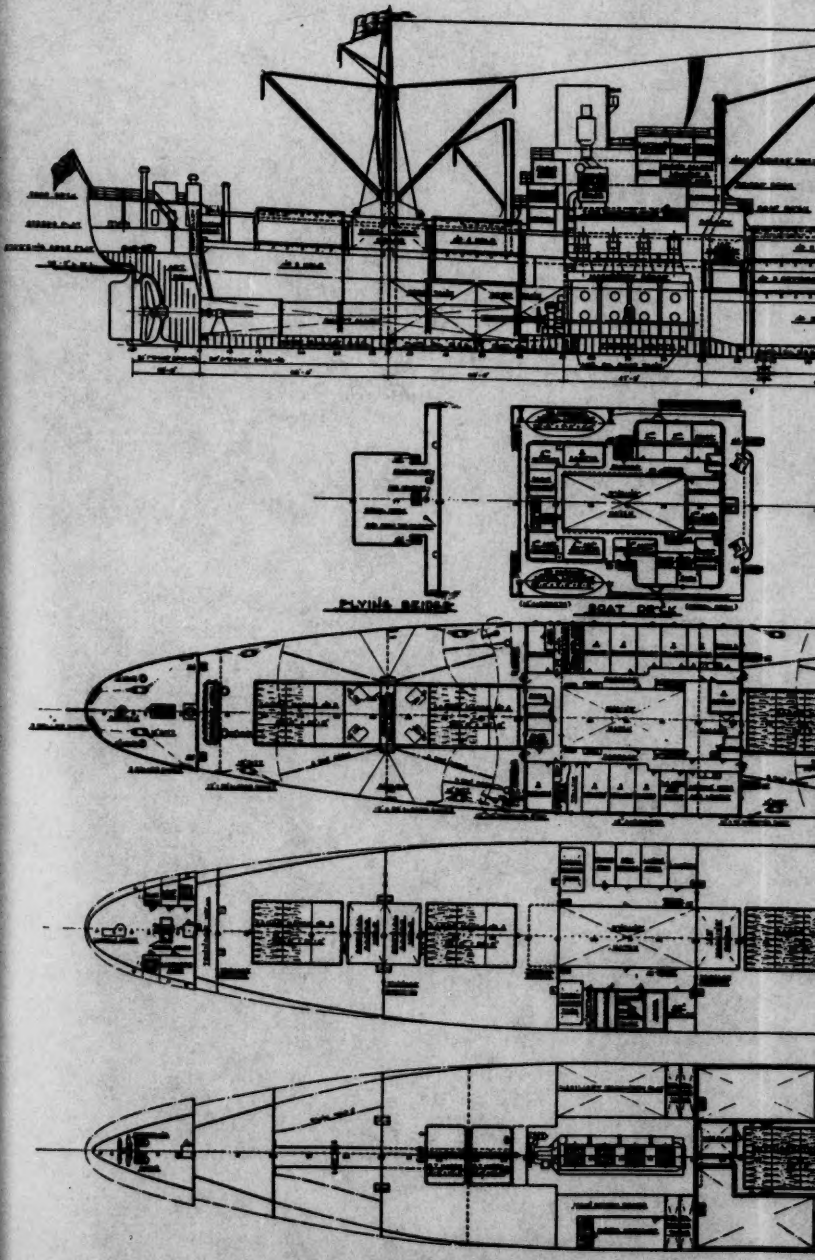
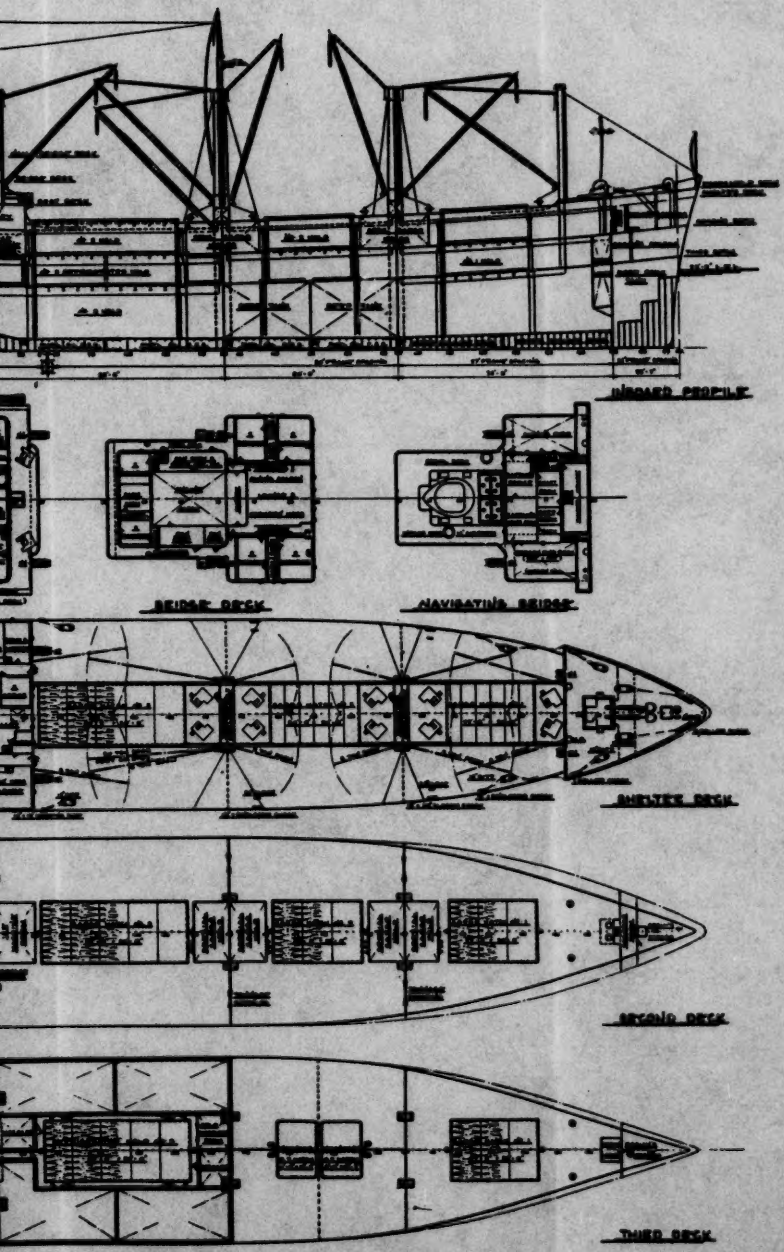


Profile and plan views, showing the general hull a



neral hull arrangement of the DONALD MCKAY.

Details of Equipment—M. S.

Pumping Equipment

Units	Service	Capacity, G.P.M.	Type	
2	Salt water circu.	2450 @ 50 lb.	Centrif.	Mo
2	Fresh water circu.	1750 @ 50 lb.	Centrif.	Mo
1	Fire	300 @ 50 lb.	Centrif.	Mo
1	Fire	400 @ 125 lb.	Centrif. 2-stg.	Mo
1	Bilge	400 @ 35 lb.	Centrif.	Mo
1	Ballast	400 @ 35 lb.	Centrif.	Mo
2	Fresh water	80 @ 100 lb.	Centrif.	Mo
1	Sanitary	300 @ 50 lb.	Centrif.	Mo
2	Boiler feed	15 @ 100 lb.	Recip.	Ste 3½
2	Cargo	500	Rotary	Mo
1	Water tr.	6 @ 60 lb.	Centrif.	Mo
1	Fuel tr.	400 @ 50 lb.	Rotary	Mo
1	Aux. Fuel tr.	20 @ 50 lb.	Rotary	Mo
2	Lube oil	350 @ 50 lb.	Rotary	Mo
1	Oil-water separator	15 @ 50 lb.	Rotary	Mo
1	Air priming	65 c.f.m. (air)	"Hytor"	Mo
1	Aux. injection	75 g.p.m. 4000 lb.	Recip.	Mo

Steam Equipment

Units	Service	Capacity	Type
1	Boiler	Oil 4,000 lb./hr. 50 lb. Exhaust 2,600 lb./hr. 50 lb.	Tubular wast and oil fire
1	Condenser	10,400 lb./hr.	Tubular
1	Fuel heater	—	—
1	Oil burner	—	—

Heat Exchangers

2	Fuel heaters	350 g.p.h.	Tubular (main
1	Oil-water separator	50 tons	—
1	Distiller	600 gal. 24 hrs.	—
1	Evaporator	30 tons, 24 hrs.	—

Deck Machinery, Electric, all G. E. mo

1	Steering gear	Elec. Hydr.	25 hp.
1	Capstan	20,000 lb./3 f.p.m. vert.	35 hp.
14	Winches	6,720 lb. 220 f.p.m. Geared	50 hp.
2	Winches	12,000 lb./180 f.p.m. Geared	50 hp.
1	Windlass	2 anchors 9,415 lb. 30 fath. chain/20 f.p.m. spur geared	50 hp.

Refrigeration

Units	Items	Capacity	Make	Motor
1	Plant	3 ton	Freon-Carrier International	7½ hp. G.E.
5	Machines, cargo	5 ton	Freon-Carrier International	10 hp. G.E.

Lube Oil Equipment

Units	Items	Capacity	Make	Motor
2	Purifiers	350 g.p.h.	De Laval	G.E. 2 hp.
2	Coolers	350 g.p.m. 100°-90°	Davis	
1	Heater	350 g.p.h. 60°-160°	Ross	

Fuel Equipment

Units	Items	Capacity	Make	Motor
2	Purifiers	350 g.p.h.	De Laval	G.E. 2 hp.
2	Heaters (Aux. Eng.)	20 g.p.h. 60°-180°	Ross	
1	Heaters (Purifier)	350 g.p.h. 60°-180°	Ross	

Units	Items
1	Softener
2	Coolers

Units	Service
2	Salt water c
2	Fresh water
1	Fire

Units	Items
1	Shaper
1	Upright dri
1	Engine lath
1	Floor grind

M. S. Donald McKay

nent

pe	Drive	Make Pump	Make Motor
trif.	Motor, 60 hp.	Worthington	General Electric
trif.	Motor, 60 hp.	Worthington	General Electric
trif.	Motor, 15 hp.	Worthington	General Electric
2-stg.	Motor, 50 hp.	Worthington	General Electric
trif.	Motor, 15 hp.	Worthington	General Electric
trif.	Motor, 15 hp.	Worthington	General Electric
trif.	Motor, 7½ hp.	Worthington	General Electric
trif.	Motor, 15 hp.	Worthington	General Electric
cip.	Steam 6½ by 3½ by 8 V.S.	Worthington	
ary	Motor, 50 hp.	Kinney	
trif.	Motor, ½ hp.	Worthington	General Electric
ary	Motor, 20 hp.	Worthington	General Electric
ary	Motor, 1½ hp.	Worthington	General Electric
ary	Motor, 50 hp.	Worthington	General Electric
ary	Motor, ½ hp.	Westco	General Electric
tor"	Motor, 5 hp.	Nash	General Electric
cip.	Motor, 2 hp.	Watson Stillman	General Electric

ent

Type	Make
Tubular waste heat and oil fired	Foster Wheeler
Tubular	Worthington
—	Ross
—	Best

gers

Tubular (main engine)	Ross
—	McNabb
—	Davis
—	Davis

all G. E. motors

25 hp.	American	Engineering	Co.
35 hp.	"	"	"
50 hp.	"	"	"
50 hp.	"	"	"
50 hp.	"	"	"

Engine Fresh Water System

ilts	Items	Capacity	Make
	Softener	60,000 grammes	Permutit
	Coolers	1,750 g.p.m. 160°-140°	Davis

Water Pumps

ilts	Service	Capacity	Power	Make
	Salt water circu.	2,450 g.p.m. @ 50 lb.	60 hp.	G.E.
	Fresh water "	1,750 g.p.m. @ 50 lb.	60 hp.	G.E.
	Fire			

Machine Shop Equipment

ilts	Items	Size	Make
	Shaper	16 in.	Steptoe
	Upright drill	20 in.	Champion
	Engine lathe	18 in. by 54 in. between centers	Le Blond
	Floor grinder	2 wheels, 2 in. by 12 in. by 1 in.	Cincinnati

Equipment on the Donald McKay

Additional Equipment Identification
Navigation Items

Items	Make
Gyro compass	Sperry
Gyro pilot	Sperry
Depth finder (Fathometer)	Submarine Signal Co.
Searchlight	Sperry
Direction finder	R.C.A.
Radio equipment	R.C.A.
Window wipers	Kearfot
Steam whistle, 10 in.	Star Brass
Air whistle	Leslie Typhon

Engine Room Miscellaneous

Items	Make
Pyrometers	Illinois Testing Laboratories
Cylinder liners	Sun
Piston rings	American Hammered
Forgings	Camden Forge and Sun Shipbuilding
Propellers	Cramp
Valves, fluid systems.	Chapman
Valves, air systems.	Crane
Scavenging blowers (rotary)	Rotary Compressor Co.
Crane (9 ton)	Maris
Rev. indicator	Electric Tachometer Co.
Eng. direction indicator	Plant Mills
Mechanical lubricators	Manzel
Governors (Aux. Engines)	Pickering
Coolers (Aux. Engines)	Andale
Engine room phones.	Control Instrument Corp.
Tank alarms	Long Island Mach. & Pattern Works
Tank gages	King Engineering Corp.
Air filters on compressors	Air Maze

The propulsion engine is a Sun-Doxford, opposed-piston Diesel of latest design, rated 6000 BPH at 92 RPM. This is a four-cylinder unit, having a cylinder bore of 32 inches and a combined stroke of 92 inches. The details of construction of this engine are discussed on another page and will not be repeated here. It is of interest to note, however, that the scavenging arrangement used is a departure from past practice of the builders. Scavenging air is supplied by two rotary blowers of Rotary Blower Co. make, mounted behind the engine and driven from the crankshaft by chains, the blower speed being four times that of the crankshaft. The blowers draw air from the engine room through Burgess silencers. During the trials a noticeable feature of this installation was the quietness with which it operated, the blowers, chain drive and induction being practically noiseless.

The exhaust from the engine is carried upward to a Foster waste heat boiler, mounted on a platform in the engineroom hatch. This boiler is in two sections, one being equipped with an oil burner, and is rated for 4000 pounds of steam per hour at 50 pounds pressure. It serves as a very effective exhaust silencer, the only other provision for silencing being a perforated plate in the exhaust pipe ahead of the boiler, which serves to break up the gas stream.

Since the auxiliary equipment on the ship is extensive and all electrically driven a large generating plant is required. It consists of three Cooper-Bessemer Diesels of 320 HP, at 500 RPM, each driving a 230-Kw. General Electric generator which feeds to a large switchboard adjacent to the main engine operating station. On the board are mounted all the various instruments and controls for the electric circuits throughout the ship.

Although the ship is at present operating on ordinary Diesel fuel, provision is made for operation with boiler oil if desired. Ross fuel oil heaters are provided, in four separate units, one of the auxiliary boiler, one for the main engine, one for the auxiliary engines, and one for the De Laval centrifuges, thus permitting the fuel for both main and auxiliary engines to be conditioned. The lubricating oil can be heated with Ross heaters and cooled by Paracoil coolers.

Fresh water is used for engine cooling, a Permutit system being provided for softening the water and Paracoil coolers for cooling it after it leaves the jackets.

Starting air is provided by three Ingersoll Rand compressors of 150 CFM capacity at 600 pounds. Although dust on board ship is not a trouble often encountered, these compressors are protected by Air Maze filters on the inlets.

Just forward of the engine room is the refrigerating room in which there are five Carrier ice machines of 5 ton capacity each, for cargo refrigeration, and a 3-ton machine for ship's stores, drinking water, etc., all being electric motor driven.

Among the instruments for protecting and controlling the main engine are included an Alnor pyrometer, with the indicator mounted on a stanchion adjacent to the control station, and an Electric Tachometer Co. revolution counter system. This latter includes a revolution counter and a speed indicator in the engine room and a second indicator in the pilot house. There is also a Plant-Mills direction indicator in the pilot house.

A noticeable feature of the *Donald McKay* is the absence of the conventional forest of ventilators projecting above the decks. Practically the entire ship is mechanically ventilated by means of Ilg blowers with air conditioning equipment attached. The hollow kingposts which support the cargo boom are utilized for supplying air to the blowers, thus getting the intakes high enough to be out of the way of spray.

Sun-Doxford Diesel in the "Donald McKay."

The Sun-Doxford opposed-piston type propulsion Diesel of the *Donald McKay* is a four-cylinder engine with cylinders 32 inches in diameter, having a combined stroke of 95 inches. It is rated 6000 BHP at 92 RPM, 6600 BHP at 95 RPM, and 7500 BHP for two hours at 100 RPM.

The bedplate is of steel plates, welded, the cross-members being arranged to receive spherical, cast-iron main bearings. The columns, five in number, are of welded steel and form A-frames over the main bearings. These frames are tied together to form a unit structure by an entablature which rests on top of and is bolted to the five frames. The entablature is made in two sections, built up of steel plates and welded, the two sections being bolted together, and provided with bores to receive the cylinders. Openings in these bores register with the cylinder scavenging posts. The rear columns of the A-frames serve to support the cast steel crosshead guides, there being three guides for each cylinder, one for the crosshead of the lower piston and two for the crossheads of the upper piston. All of these guides are water cooled.

The cylinders are of usual Sun-Doxford construction, each consisting of a liner, open at both ends, with a water jacket shrunk on the center portion. Near the lower end is a circumferential ring of scavenging ports, so shaped as to give the air a swirling motion as it enters the cylinder. The exhaust ports are located near upper end of liner, so that uni-flow scavenging is obtained.

Bores through jacket and liner at the midpoint receive an injection valve and air starting valve on front side, and a second injection valve, a relief valve and a brake valve on back side. The liners are given a final finish by honing, thus assuring a minimum amount of initial wear-in.

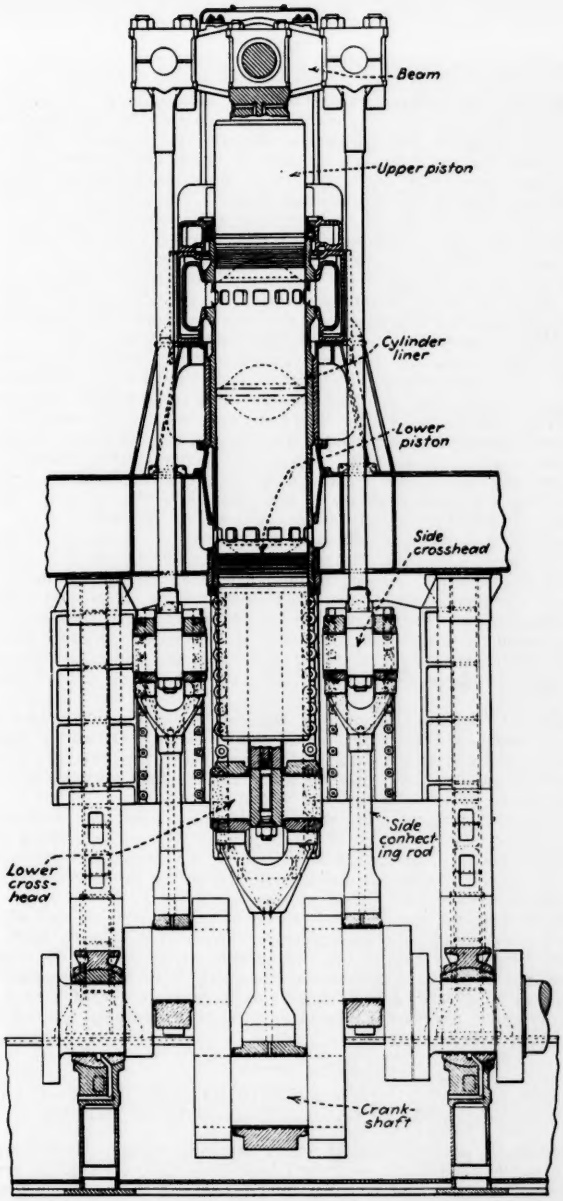
The exhaust manifold, attached to the backs of the cylinders, is built up of steel plate, welded, and is provided with three expansion joints. The exhaust is led to a waste heat boiler, connection to the boiler casing being made by means of a flexible plate joint.

The crankshaft is of forged steel, built-up, and consists of four separate sections, one three-crank section for each working cylinder.

The working pistons are of cast iron, made in two parts, the skirts being bolted to the rods. The heads have concave crowns, so that when the pistons meet at end of stroke the compression space is of approximately spherical shape, and each is provided with five rings of the plain snap type. Each lower piston is attached by a short piston rod to a forged steel crosshead which works in the center guide. Connection to the center crank is by means of the usual marine-type connecting rod, the length of the rod being 3.82 times the length of the crank throw.

Connection of each upper piston to the crankshaft is by means of a beam attached as its center to the piston and connected at each end to a side crosshead by means of a rod passing down through the cylinder entablature. The two side crossheads are connected to two cranks, one forward and one aft of the center crank, by connecting rods having a length equal to 5.62 times the crank throw. The pistons are fresh-water cooled, the inlet and outlet connections being made to the crosshead of lower piston and crossbeam of upper piston by means of swinging arms and flexible rubber tubing.

Two camshafts, one at the back of the cylinders and one at the front, are supported in bearings on top of the cylinder entablature and driven by gears and a vertical drive shaft from the crankshaft. The rear camshaft operates the rear injection valves and the brake valves, while the front shaft operates the front injection valves and the air starting valves. Reversing is accomplished through the medium of the front camshaft which is slidable in the direction of its length and provided with ahead and astern cams.



LONGITUDINAL SECTION THROUGH ONE CYLINDER SHOWING DETAILS OF CONSTRUCTION OF THE "DONALD MCKAY'S" MAIN ENGINE.

The rollers on injection valve levers bear directly on the cams, so that no push rods are required. The injection valves are of the balanced piston type and are attached to the cylinders so that the fuel is injected in horizontal sprays into the space between the pistons. It should be mentioned that the fan-shaped spray that was a feature of the original Doxford engines has never been used in the Sun-Doxford design. The spray nozzle used in the latter discharges through a circle of small holes, producing more of a cone-shaped spray. Its effectiveness was demonstrated on the *Donald McKay* engine by the colorless exhaust obtained at all speeds.

An interesting feature of the engine is the braking arrangement for stopping the engine quickly when maneuvering. Mounted in the rear of the engine above the camshaft is a group of valve boxes, one for each cylinder, in each of which is a piston valve operated by a cam on the camshaft.

The valve boxes are in communication with and control the operation of brake valves mounted on each cylinder. The cylinder valves are connected in pairs, each pair being in communication with two cylinders, the cranks of which are 180 degrees apart. The cams are timed so that when the valves are cut in during maneuvering, air is discharged to a diaphragm operating the cylinder valves. Both valves in the two cylinders whose cranks are 180 degrees apart are opened when the pistons are at the extreme ends of the stroke and the compressed air in one cylinder is allowed to fill the other cylinder in which pistons are at the outer end of the stroke.

Some of the compressed air escapes, but when the ports are sealed on the closing stroke a considerable volume of air is entrapped at a pressure in excess of the normal scavenging air. The final compression in the supercharged cylinder is higher than that employed for combustion. Releasing the compression in one cylinder on the expansion stroke and increasing the compression on the compression stroke of the opposite cylinder absorbs the inertia in the shafting and propeller, and brings the engine to a stop quickly. During the braking operation the fuel is cut out and no cold air enters the cylinders.

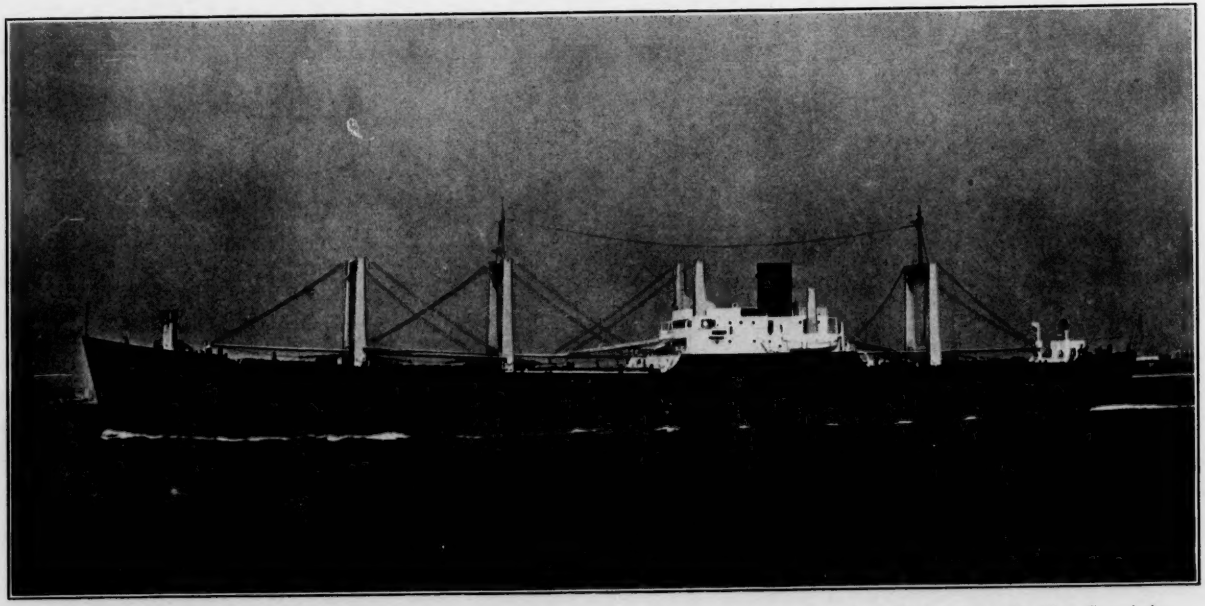
Fuel under constant pressure is supplied to the injection valves by four plunger pumps, assembled in a single unit at the after end of the engine and driven by gears from the thrust shaft. For maintaining pressure in the fuel lines before the engine is started a Watson-Stillman vertical, two-plunger pump, driven by a two-horsepower motor, is provided.

Our readers will recognize the foregoing description as a verbatim copy of an article which appeared in our September, 1937, issue, dealing with the propelling engine of the tanker *Louisiana*. It is repeated here for the reason that the engine is an exact duplicate of that in the *Louisiana*, except as to cylinder dimensions and method of scavenging.

This is the first Sun-Doxford engine to depart from the use of the attached, crank driven scavenging pump. Two rotary blowers, made by the Rotary Compressor Blower Co., are installed at the back of the engine and driven by Link Belt chains from the crankshaft. These blowers, each having a capacity of 13,000 c.f.m. at three pounds pressure are of a new design, featured by an automatic change-over valve which permits reversal without interfering with operation.

S. S. *CHALLENGE:* FIRST OF THE STEAM DRIVEN C-2 CLASS DEMONSTRATES RECORD FUEL ECONOMY.

This article describes United States Maritime Commission's steam drive C-2 vessel in comparison with the Diesel drive C-2 vessel of the preceding article. The abstract is from the "Pacific Marine Review," San Francisco, Calif., August, 1939.



Photograph by Courtesy of the United States Maritime Commission.

S. S. Challenge, Turbine Driven Cargo Vessel, C-2 Type.

Recent trials of the first C-2 steam turbine drive ship, the *Challenge,* built by the Federal Shipbuilding and Dry Dock Company, indicate that unofficially her propulsion machinery has made a world record on fuel economy for marine power plants with a figure of 0.552 pounds of oil per shaft horsepower hour for all purposes. We understand that the second ship of the six sisters building at Federal, the *Red Jacket,* is slated for a full Navy standard trial at the Rockland measured mile and that results obtained there will be official and beyond question.

This remarkable fuel economy has raised considerable interest in the ship's power plant, and we are therefore publishing this description of her boilers and turbines.

The *Challenge* and her five sister C-2 ships being completed by Federal Shipbuilding and Drydock Company are propelled by highly efficient General Electric turbines and gears. The design of this equipment is based on G-E experience in equipping more than 400 ships with geared-turbine propulsion in the last twenty-five years.

The G-E turbine unit in the *Challenge* is of the cross-compound impulse type and consists of a high-pressure and a low-pressure turbine. It is connected to the propeller through double-reduction gears.

The rotor of the high-pressure turbine rotates at 6100 RPM and that of the low-pressure rotor at 4050 RPM.

Normal rating of the turbine-gear set is 6000 horsepower at 92 RPM propeller speed and it can maintain a continuous output of 6600 HP.

The turbines are supplied with steam at 440 pounds gage and 740 F. total temperature. They exhaust into the condenser at 28½ inches vacuum. The astern turbine for reversing is built into the low-pressure turbine casing. It normally rotates in a high-vacuum to keep down rotating losses.

High sustained economy is built into the G-E turbines for these six C-2 vessels by careful design and manufacture of all parts of the steam path. The nozzles and buckets forming the path consist of accurately shaped sections made of materials selected for their corrosion and erosion-resisting qualities. Steam is at a practically constant pressure after it leaves the nozzle, during its passage through the buckets, and in the space surrounding the wheel. Excellent steam distribution is obtained because of the large dome which forms part of the low-pressure turbine.

The diaphragms, of which the nozzles are a part, are made from welded steel boiler plate with welded-in, accurately-spaced nozzle partitions of non-corrosive material. The buckets are dovetailed into the wheels with a tight machine fit which does not require calking and which will stay tight after years of service.

In the lower stages, the diaphragms are arranged to collect moisture that is thrown out centrifugally and to drain it to the condenser. This improves the efficiency and aids in preventing bucket erosion.

The turbine casings are split on the horizontal center. Joints are metal to metal. The rotors are of solid forgings with the wheels machined integral with the shaft. A steam deflector between the ahead and the astern buckets is also machined integral with the shaft.

To minimize steam leakage along the turbine shaft, packings are used at the high-pressure and low-pressure ends. They consist of multiple segmented carbon and metallic rings.

The carbon packings are individual smooth rings made of best grade carbon, and when in service they attain a high polish which minimizes friction and adequately seals the unit.

Metallic packings are of the labyrinth type and are made from a special alloy which, if in contact with the shaft, will not cause local heating and consequent distortion of the shaft.

Packing rings, whether metallic or carbon, are divided into segments for easy inspection or repair, and each ring is held firmly in place by flat steel springs which retain their strength in high-temperature service.

The main bearings of the turbine are of the babbitt-lined, spherical-seated, self-aligning type, pressure-lubricated and cooled by oil from the ship's lubricating system. They are finished to exact dimensions to permit interchangeability, and can easily be removed without disturbing the turbine shaft or any part except the bearing caps.

A thrust bearing is furnished to maintain the correct axial spacing between the stationary and rotating parts, and to compensate for the relatively small unbalanced thrust in an impulse-type turbine. This thrust bearing is of the improved tapered land type consisting of a hardened steel collar running against plates faced with babbitt segments set at a slight angle to the runner to give tapered oil films between the runner and the babbitt-faced segments, or lands.

This thrust bearing requires no adjustments in service, and besides being compact, is designed with a liberal margin of safety. As an additional precaution, the thrust bearing has "squealer rings" which rub and temporarily act as a thrust bearing to prevent damage to the rotating parts if the thrust-bearing babbitt should wear unduly.

DOUBLE REDUCTION GEAR.

The reduction gear, of the double-helical type, is of a design and construction of proved durability and efficiency, and retains proper running contact under continuous and extended service. It consists of two high-speed pinions each driving a high-speed gear. The two high-speed gears are connected to two low-speed pinions, which in turn drive the low-speed gear.

The steel casing enclosing the rotating elements is of heavy, rigid construction designed to retain the gear and pinion bearings in accurate alignment. To facilitate removal for repairs or inspection, the casing is divided into several sections. The lower portion of the low-speed gear casing is split on the horizontal center line of the low-speed gear shaft. The upper portion of the casing has pinion covers split on the horizontal center lines of the pinions. The joints between the casings are made right without gaskets by an improved lapping process which prevents the escape of oil vapor.

The high-speed gear wheels are of the cast-steel type.

The low-speed gear is of the fabricated type, consisting of a forged shaft with integral coupling, a cast-steel hub with plates, and rim. The plates are welded to the rim and hub. The gear wheel is annealed to relieve all internal strains.

The pinions are solid with their shafts and made of nickel steel forging properly quenched and tempered. They are so proportioned as to insure uniform distribution of tooth pressure over the face.

All flexible couplings are of the high-speed type, dynamically balanced and arranged for proper lubrication of the wearing parts.

The bearings of the gear are of the straight-seated, babbitt-lined, pressure-lubricated type. Each high-speed pinion, high-speed gear, low-speed pinion and low-speed gear has two bearings.

The main thrust bearing is of the Kingsbury type, and is arranged in a housing on the forward end of the low-speed gear casing. The lower part of the thrust housing is integral with the lower-half gear casing and arranged with ample footing for heavy bolting to the ship's structure.

The turning gear is of the motor-operated type connected through a clutch to one of the high-speed pinions. The motor is reversible and is provided with magnetic control panel and drum controller.

The six thousand shaft horsepower of the *Challenge* originates in two marine steam generators of unusual interest. They are based on a design known as the "D" type which has been widely used in the American Merchant Marine since 1935, when the first boilers of the type were fitted to the *R. P. Resor* and the *T. C. McCobb*. In each case two boilers have been set in a single steel casing to provide an arrangement which makes for maximum compactness and accessibility.

The furnace of the original "D" type steam generator was fitted with water-cooled floor, side wall and roof. Subsequently, additional water cooling was added in the back wall—opposite the oil burners. In the new class C-2 steamers, however, the ultimate in water cooling of furnaces has been developed and in addition to the back wall, water cooling is used in the front wall also, the tubes being so arranged as to permit installation of the burners between the rows of tubes. In addition, there are a greater number of tubes in the floor and in the roof, thus providing additional circulation capacity for the side and end walls.

The designation "D" type is taken from the shape of the boiler unit, which approximates a capital "D." A large steam drum is placed vertically above a somewhat smaller water drum and connected to it with rows of boiler tubes. The furnace is set at the side and occupies the space corresponding to the curved portion of the capital "D." Placing the furnace at the side of the heating surface instead of below it permits the use of as large a furnace as necessary to thoroughly burn the fuel before it enters the tube bank. Sufficient time element is essential for complete combustion. Between the third and fourth rows of boiler tubes from the furnace there is space for the installation of a bare tube convection superheater—the first three rows of boiler tubes are larger than those in the last passes, and form an effective screen between the super-heater and the furnace.

Three oil burners are arranged one above the other in a vertical row at the front of the furnace, thus providing maximum clearance between the edges of the flames and the walls of the furnaces. Gases leaving the furnace pass through the first bank of tubes and upwardly across the super-heating surface to the top of a vertical steel baffle, thence downward parallel to the tubes in the last bank of the boiler to the water drum. The gases then turn upward and flow vertically, first past sixteen rows of economizer tube surface and then through the air heater to the stack.

A completely water-cooled furnace of tubular design is distinctly uncommon on shipboard but seems destined to gain much favor. The provisions for ample circulation must be thoroughly worked out and in this case the headers at the front, rear and side of the furnace are fed with water from the water drum. Discharge tubes from collecting headers at the top of the water walls are run directly into the steam drum, below the water level. The water wall tubes are set as closely together as possible and are virtually tangent, thus creating the equivalent of a steel-lined furnace.

The operating pressure is 450 pounds per square inch and the final steam temperature 765 degrees F. The super-heater is provided with mechanical steam soot blowers. Each superheater element may be removed without disturbing more than two others; the superheater is of self-draining type.

The economizer is of extended surface, cast iron, marine design fitted with soot blowers to maintain clean surfaces without hand lancing. The cast iron rings are shrunk upon seamless steel boiler tubes and give six times the area for heat absorption from low temperature flue gases that would be presented

by the same length of bare tubing. In addition, the cast iron protects the tubing from corrosion. Feedwater for the boiler flows downward through the economizer, counter current to the flow of flue gases, thus effecting maximum efficiency.

Final heat recovery is made in a tubular air preheater in which the tubes are arranged horizontally and through which the air for combustion is passed; the flue gases flow outside of the tubes.

The general advantages attributed to this type of marine steam generator include:

Maximum absorption of radiant heat in the furnace.

Minimum loss of heat by radiation.

Superheater accessibile for external cleaning from the furnace, if necessary.

Maximum heat recovery from furnace gases through the combined use of economizer and air preheater in series.

Fourteen mechanical soot blowers insure cleanliness.

The effective operation of such a unit must necessarily result in high efficiency, and the trial runs of this steamer showed flue gas temperatures in the neighborhood of 260 degrees F. at normal rating. The efficiency guarantee of 88 per cent was well exceeded.

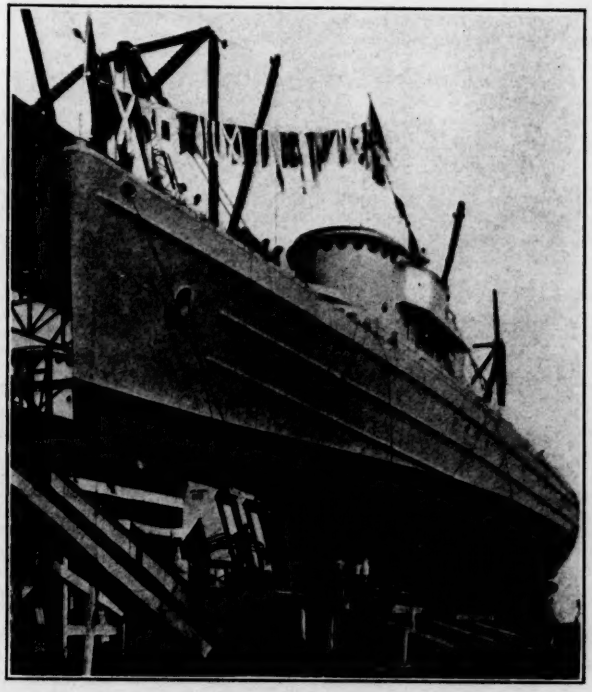
Mechanical draft is provided through the use of forced draft fans which blow the air for combustion through the air heater and down across the end of the casing to the burners. Careful provision is made for a cool fire room in the heavy insulation with which the steel casing of the boiler units is lined. Ample refractory is used where the gas temperatures are high, and two grades of insulation used between it and the steel paneling.

U. S. S. *NAVAJO:* OCEAN-GOING TUG LAUNCHED AT MARINERS HARBOR.

This vessel and her sister ships, the U. S. S. *Cherokee* and the U. S. S. *Seminole* are the first large seagoing Navy tugs built for a number of years. The article is reprinted from the August 26, 1939, issue of the "Nautical Gazette," New York, N Y.

The first of three U. S. Navy ocean-going fleet tugs under construction at the Staten Island Yard of Bethlehem Steel Company, Shipbuilding Division at Mariners Harbor, was successfully launched August 17th. Miss Olive Rasmussen, daughter of Mr. G. Rasmussen, foreman riveter of the Staten Island Yard was selected by the company to christen the vessel the U. S. S. *Navajo.*

These three vessels, of which the U. S. S. *Navajo* is the first to be launched were contracted for on August 15, 1938, to be delivered within 18, 20 and 22 months, respectively. An interesting feature of their contract specifications is that they are built to the rules of the American Bureau of Shipping except for special features involving Navy design not covered by the American Bureau of Shipping rules. This is one of the first instances in which the Navy Department and the American Bureau of Shipping have collaborated in the design and inspection of vessels for the Navy. A feature of the design is the inclusion aft of an electrically driven, automatic-acting towing engine, one of the first of this type of appliance installed on any American vessel.



U. S. S. "NAVAJO."

The main characteristics of the vessel are as follows:

Length overall, feet and inches	205—3
Length between perpendiculars, feet and inches	195—0
Breadth (molded), feet and inches	38—6
Depth (molded), feet and inches	22—0
Mean Draft, feet and inches	14—3
Speed (no tow), knots	16.25

The propelling machinery consists of four Diesel engines, directly connected to D.C. generators. Four propelling motors drive a single screw through a reduction gear, at approximately 140 RPM. Storage space is available for 95,000 gallons of fresh water. A 20-ton boom with electric winch is provided aft.

Accommodations are provided for 5 officers, 6 chief petty officers, a crew of 50 enlisted men, and for a passenger list of 4 officers, 3 chief petty officers, and 28 enlisted men, making a total of 96 men. Commissary spaces include a wardroom, pantry, scullery, galley, and separate messes for officers, chief petty officers, and crew. A mechanical ventilating system is used for the entire ship.

The navigation equipment includes two navy compasses, a gyro compass with five repeaters which are electrically connected dials located in various parts of the ship, complete radio communication facilities and a radio direction finder. The steering gear is of the electric hydraulic type with hydraulic telemotor control.

One 30-foot motor launch, a 26-foot motor whaleboat and three 25-person floats comprise the life saving equipment. Independent fire extinguishers of the foam generator type will be used in the machinery spaces, and carbon dioxide fire extinguishers in lamp, paint, and oil rooms. The vessel will have two salvage pumps, each with a capacity of 500 gallons per minute.

PRINCIPLES CONCERNING THE MAIN PROPULSION UNITS OF WARSHIPS.

This article is by Korvettenkapitan (Ing.) Dipl.-Ing. K. Thannemann. The original was printed in Zeitschrift des Vereines Deutscher Ingenieure, Berlin, Germany, July 15, 1939. The translation and rewriting from the German is by Clyde L. Frear, Engineer of Materials, Bureau of Engineering, Navy Department. Metric values have been transposed in the tables to their equivalent English units. The article is basic in character and discusses broadly the military characteristics to be considered in the design of a main propulsion plant.

The complicated relationship between the main propulsion unit and the warship as a whole presents numerous, apparently contradictory demands, which are difficult only until everything bearing thereon has been considered. It is not necessarily by the best technical solution, but by consideration of the most suitable military application, that superior military requirements are met. Highest speed, great cruising range, service reliability, power stability, and independence of shipyards must be guaranteed a modern warship through its main propulsion unit.

The various problems for the conduct of naval warfare, in the course of a long and never ending evolution, have led to very specialized classes of warships (1).* The most important and best known of these are: battleships, air-

* The numbers in parentheses refer to the bibliography at the end of this article.

craft carriers, cruisers, destroyers, torpedo boats and submarines, as well as speed boats. In addition to these there are vessels for special work, for example, mine sweepers.

Every warship fulfils a definite purpose in combat which is made possible by a combination of individual battle values. These can be of an offensive variety, due to the armament; or defensive, as security from sinking and capture. Individual combat value, speed, and cruising range occupy a double position in the design of the power unit. They can be of value offensively as well as defensively (2), in which case the different classes of ships are distinguished from each other corresponding to the different military requirements, such as the possibly one-sided emphasis on the combat value, the speed, or the cruising range. In the same manner, different proportional weights have been given to the different classes of ships so that the individual combat value of the whole weight, also the displacement, will be correctly allotted. Two of these weight groups are, speaking from a purely technical standpoint, the main driving unit and the fuel supply, which make possible a calculated cruising range. From this it becomes clear that, in the different classes of ships the power plant must be correctly developed to suit the special purpose for which it was designed.

The technical superiority of a warship over one of the same class in some other navy presupposes, with the present position of technical development with all great powers, that

1. The future problems, also the methods of their application in wartime, are already known to the military personnel, and their disposal assured,
2. Everything else will be prudently limited for the necessary essentials of superiority and the making of the correct decisions, and
3. That the latest knowledge and technique will be willingly and correctly used in the design and construction.

That which probably makes the design of the power plant of a warship the most difficult is the fact that there is almost no flexibility of plans, but even the slightest arrangement must be adapted and subordinated to the greater importance of the design of the whole ship and the particular requirements of the navy. There is required a protracted compromise between the military demands and the technical possibilities, the highest feeling of mutual respect, supported by a close liaison between the demands of the line officers and the planning officers as well as between the engineers and the builders. A more complete result is possible only when there is retained over these an individual who is an authority in this line, who is able and willing to make difficult decisions based on learned judgment coupled with wholesome foresight.

The development of the ship's construction, construction of the machinery, armament, and even the medium of information may proceed rapidly. With a large ship, however, several years elapse from the first planning to the commissioning, during which many changes may occur, occasionally even in the strategical and the political situations. A warship can never be considered entirely completed or entirely satisfactory when, even during its construction, continuing improvements and the newest conceptions of design are being considered and applied.

In the case of a warship, the proof whether a development is correct comes generally only during an emergency, an engagement. The preservation or destruction inexorably decides the long work of the preceding decade and the previous decisions of the responsible personnel.

THE MAIN PROPULSION UNIT IN RELATION TO THE WHOLE SHIP.

By the power plant of a warship is understood the main propulsion unit with its attendent auxiliaries and auxiliaries for general purposes. The size of the main propulsion unit depends upon the class of ship, the ship's resistance, and the military demands for speed. The general purpose auxiliaries will, on the other hand, depend upon the size of the ship, the current demand, the armament, and medium of information, and the size of the crew. The extensive electrical plant possesses no independent fighting value. It is but one of the almost indispensable aids to the conduct of the ship and above all for the servicing of the armament and communication system, and is able decisively to influence the combat power.

There is no sharp demarcation between the main driving unit and the auxiliary engines, and the demarcation is not necessarily the same in all navies. In the strictest sense the main propulsion units, the main auxiliaries, and the general purpose auxiliaries have nothing to do with each other, even though they may use the same motive power and are interconnected in mutual service. They require separate and individual consideration. The following description, therefore, is limited to a consideration of the main propulsion unit.

MAXIMUM SPEED.

As far as military demands are concerned, the maximum speed of a warship is one of its most important fighting values. It depends essentially on the special function of the class to which the ship belongs, on the maximum speed of similar older ships of the same class, and on the combat power of a superior enemy.

The maximum speed corresponds to the highest power that the main driving unit can exert. It can usually be continued but a short time and only by greatly overloading all parts of the power plant. Distinguished therefrom is the highest continuous performance of the engines which in general amounts to approximately eighty per cent of the maximum performance. A modern ship, equipped with oil burners, can travel almost without limit at the maximum cruising speed as long as the fuel supply lasts. With coal firing, which is now almost completely discontinued, the speed was almost certain to decrease because of sooting and necessary cleaning of the fires, exhaustion of the crew, and difficulty in carrying the required coal from remote bunkers.

Since the world war a remarkable change has taken place in the conceptions concerning the most suitable purpose of the battle fleet (7). Reduction in the number of ships, increase in the size of individual ships, improvement in armament, adaptation of aerial warfare, and above all, the increase in the maximum speed of the battleships are the chief characteristics of the post-war developments. Above all, with the partially seagoing navies* which are in an unfavorable position as compared with the fully seagoing, the increase in the maximum speed has found a particular consideration. This has compelled the other navies to do the same. The increase in the speed of the battleships from 20 to 23 knots during the world war to 30 to 33 knots to-day, Table 1, must be applied to the future construction of cruisers, destroyers, and particularly aircraft carriers in such a manner that these will have the greatest possible speed over that of the battleships. This is unquestionably necessary in order that, working together with the individual

* Ed.—Partially seagoing navies are designated as those which operate primarily in the relatively protected inland seas of Europe.

battleships, they can clear the opposing heavy combat forces and attack favorably or be able to turn aside quickly enough to be able to fulfil the special functions of these lighter classes of ships. The speed of today's cruisers ranges from 32 to 35 knots, and that of the destroyers and torpedo boats from 38 to 45 knots.

With the increase of the maximum speed, the power of the main driving units which must be built into the ships has increased rapidly. The largest power units which have ever been built into a warship are those of the American aircraft carriers *Lexington* and *Saratoga*. These develop a maximum of 210,000 shaft horsepower and produce a maximum speed of 34.5 knots.

WEIGHT PROPORTION OF THE MAIN PROPULSION UNITS.

In the different classes of ships the main propulsion units have different weights in proportion to the displacement. In spite of the considerably increased power performance, the proportion has remained fairly constant for each class of ships, and in nearly all fleets. The increase in speed has not been attained at the cost of other fighting values, but almost exclusively by the removal of extraneous parts from the machinery, by lower unit weights, and by decrease in the space requirements. Weakening of the combat strength in the future cannot be tolerated, therefore further increase in speed can be secured only through engineering development of the power plants. Table 2 shows the proportion of total weight taken up by the main driving units for different classes of ships, and Table 3 gives a comparison between two old cruisers of the German navy.

UNIT WEIGHTS OF THE MAIN PROPULSION UNITS.

Of all modern developments, the relation of unit power to weight of the driving unit is probably the most easily understood. The machines with the required high outputs can only find their place in a modern ship when they are built so light and space-saving that such high power outputs can be justified by technical and military considerations. Maximum number of revolutions of the main and auxiliary engines, lowest constructional weight of all parts, highest grade materials, closest calculations, and closest agreement of all parts with each other are the means by which this end may be attained. A favorable fuel consumption is not usually combined with the lowest constructional weight. Table 4 from a French source (3) shows these developments over a period of approximately twenty-five years. This shows that the unit weight has fallen considerably and that unit weights for large ships compare favorably with those of lighter vessels. The same development is shown by the other great sea powers.

The main propulsion units of large ships must always be built heavier than those of light, fast, and small ships. Entirely apart therefrom is the fact that the increasing dimensions always cause greater weight demands by other parts of the power plant such as shafts, funnels, piping, etc., and place entirely different demands on the stability of heavy ships and in turn on their driving units. A combat ship must be able to withstand heavy engagements and always remain capable of moving and fighting in spite of severe damages. In the case of light ships, their protection lies mainly in their higher speed and in the presentation of a smaller target.

The figures in Table 5 can probably be considered as correct for present-day ships. With the high combat value of the submarine, it must be realized that it must possess a double power unit—Diesel motors for travel on the

surface, and electric plants with heavy storage batteries for travel below the surface—which accounts for the increased unit weights for these small boats. For a comparison, the unit weights of modern merchant ship power plants are given (4):

Water tube boilers and gear connected turbines....130 to 180 pounds per HP
Diesel motor plants..... 220 pounds per HP

Nothing shows the difficulties of the engineer to better advantage than a comparison of the design of the warship motive plant and its performance demands.

SPACE REQUIREMENTS OF THE MAIN PROPULSION UNIT.

It is easily understandable but scarcely demonstrated by any published data that, with the lowering of the unit weight, it is necessary to attain a proportional decrease in the space required by the main propulsion unit because the complicated fire control apparatus, charting rooms, and the communication systems of today require more space than formerly. Table 6 compares five similar large British cruisers. It will be seen that the power output was 6.5 times as great in 1934 as in 1894 and 2.5 times as great as in 1910 for the same size ship, approximately the same armament, and almost the same man power.

Today, in the design of warship power units, it is more difficult to keep within the required space limit than it is to keep within the specified limit of weight. The smaller the operating space the more difficult it is to detect small operating troubles or even injuries suffered in battle and to repair or at least confine them. A beneficial moderation is needed, the sensible limits of which are that this reduction in usable space will not be carried to such extremes that the necessary maintenance and repair cannot be carried out by the means aboard ship, or will lead to the undesirable expenditure of personnel and time in the repair of troubles or even to undesired dependence upon shipyards.

MAXIMUM SPEED AND SHAPE OF THE SHIP.

The relationship between the form of the ship and the ship's resistance at a calculated maximum speed will not be considered here. It must suffice to mention that the wave form produced by the cruising ship has considerable influence on the ship's resistance. A particular bow and stern wave system is produced which superimpose themselves favorably or unfavorably to increase or decrease the wave resistance according to the speed of the ship V (knots) and the length L (feet). The resistance is greatest at the point of resonance between the two wave systems. There is a close relationship between the most favorable ship form and the desired maximum speed. The most important influence is the ratio of speed to length, $V/\sqrt{L}$.

Tables 3 and 6 show the measurements for a series of cruisers. These show, first, that the value for $V/\sqrt{L}$ lies between 1.05 and 1.43; and that the value also depends upon the displacement. It is naturally different for different classes of ships but varies only slightly in ships of the same class in all navies, Table 7.

Tables 3 and 6 show further that with increase in maximum speed the length of the ship increases correspondingly, the ship becomes slimmer, and with the same displacement, the draught decreases. A decrease in the draught, however, does not necessarily signify a decrease in volume. As the armor decks of larger ships will draw a maximum of three to six feet above the construction water line, these decreases in draught frequently bring undesirable decreases in the space available for the main propulsion units.

These indications must suffice here. They will serve to show the various relations of the main propulsion unit to the ship for which it is built, and how strongly the design of the driving unit and that of the whole ship influence each other.

THE MOST IMPORTANT OPERATING DEMANDS OF THE MAIN PROPULSION UNIT.

The operating demands which are placed on the main propulsion unit of a warship are disproportionately greater than on a merchant ship or even a stationary unit. It is demanded of a warship that it travel and steer safely, under its own power when docking, in locks, or in difficult waters at its lowest speed without towing, cruise on long trips at 10 to 15 knots, run during tactical practice at 20 to 26 knots, and travel during engagements or in similar peaceful maneuvers at its maximum speed. The main driving unit must also work under widely varying and quickly changing rates. During peacetime the cruising requires but a fraction of the maximum output. The variation in demands are often amazingly abrupt. Within a few minutes the power plant must be able to increase from the lowest to the highest speed and within the space of a few seconds the boiler output must be capable of falling from full load to perhaps ten per cent of capacity. With these requirements there must be no smoke rising from the funnels and no safety valve blow-off. The tactical application of the ships and above all, cruising in close formation does not permit a limited range of speed, especially in the sphere of action.

The most important demands of the main propulsion unit are those of endurance in open sea operation. Those necessary for such endurance may be classed as follows: Service reliability, power stability, cruising range, and independence of shipyards.

SERVICE RELIABILITY.

Service reliability is, without doubt, the most important of all demands. Each individual part of the power plant must be fully equal to the operating demands, and must not cause trouble, even when the ship is breaking through heavy seas or wallowing heavily from side to side. During an engagement the ship must navigate at its highest speed. Any deficiency or any trouble in an important part of the unit is sure to lead to a reduction in the speed with a resultant tactical disadvantage. Such a ship can no longer hold its place in the formation. It must either fall out and lag behind and perhaps be captured, or the whole formation must reduce speed correspondingly. The service reliability is also of supreme importance in weakening the enemy.

Serious operating difficulties in the power plant, such as trouble with or serious damage to the auxiliary machinery, damage to turbine blades, splitting of boiler tubes, etc., can seldom be repaired by means aboard ship. They necessitate putting into a yard and the consequent time-consuming repair work, lowering the combat power of the fleet, hindering the service of the whole crew, and deranging the constructional facilities of the yard. The choice of the most suitable material, and the laboratory and service testing of all innovations is, therefore, one of the most important undertakings in order to insure serviceability and prevent a decisive reverse. Costs must not be considered in such cases.

POWER STABILITY.

By the power stability of a main propulsion unit is understood the possibility to maintain the seaworthiness and maneuverability when troubles occur in the plant due either to operating damages or action by the enemy. Upon this one thing has depended the choice of the method of propulsion, whether

steam engines (turbine or reciprocating) or motors, the arrangement of the plant into a closely combined or a widely separated unit, the position of the unit in relation to the propeller and shaft, and the extent of duplicate auxiliaries, transmissions, and connections. Increased power stability requires a corresponding increase in the unit weight, as the stability of the driving unit must correspond to that of the entire ship. In the case of a light, fast ship without full protecting armament, it is unnecessary to supply it with a powerful, divided power plant. The protection of this kind of ship lies in its speed and the certainty of the power plant, and the weight of the plant should be sufficient only for these two demands. On the other hand, a battleship must be able to endure being heavily hit without having to fall out and be unable to travel. The power plant must, therefore, be divided into several parts and different operating stations so that bunched hits will not totally disable the ship. Duplicates must also be provided for all especially important auxiliaries. All of these combine to increase the weight of the power unit on the heavier ships. See Table 5.

The service strength of a warship power plant depends to a large extent on the military and professional services of the men and their officers. A close liaison between the line officers and the design division is necessary for the practical utilization of practical experience gained during warfare and during peacetime battle practice.

CRUISING RANGE.

The cruising range, or in other words, the distance which a ship can travel without replenishment of the fuel supply, depends upon the required speed, the economy of the driving unit, and on the size of the fuel supply carried.

The engine output increases approximately as the cube of the speed, and in the range where the speed-length ratio $V/\sqrt{L}$ lies between 1.00 and 1.75, the proportion is still greater. The economy of a warship power plant can only be calculated on the basis of the energy content of the fuel rather than on the cost of the fuel. This is a noteworthy condition as compared to merchant ships and stationary power plants. With a warship it is necessary to determine by what means the greatest military performance can be attained. Higher costs should never be considered to the detriment of a warship's operation. Operation with maximum economy, that is with minimum fuel consumption, is impossible with a warship because of the fact already considered that such a ship must travel at greatly varying rates of speed. Table 8 shows for an older destroyer that the fuel consumption, when cruising at approximately five per cent of the maximum power output, is nevertheless 37 per cent higher than with the highest continuous travel using approximately 95 per cent of the maximum output. The most favorable fuel consumption over the greatest speed range is an essential demand of warship power plants. The higher the maximum speed, the greater will be the disproportion to the usual cruising speed and the more difficult will it be to retain low fuel consumption at increased cruising range.

Table 9 shows the general improvement in the fuel consumption since the introduction of steam turbines and oil-burning equipment on warships. From 1915 to 1925 there has been attained a reduction from approximately 1.30 pounds per SHP to about 0.80 pound per SHP, or about 40 per cent reduction. The values indicated for 1925 are also valid at the present time as the endeavors of the last few years have been in the direction of considerably increasing the maximum speed. Outwardly, light construction permits of neither weight nor space for new arrangements which would improve the economy. Highest maximum speed and economic operation at low cruising

speeds are technically opposite demands. Table 9 shows, in the case of British cruisers built between 1919 and 1931, apparently constant power performance, maximum speed, unit weight, and floor space for the main propulsion units. The improvement in the fuel consumption has resulted almost entirely from the introduction of superheated steam. The steam pressure has only lately been increased abroad.

The demand for increased cruising range necessitates considerable increase in the weight and space for the fuel supply. In this connection the introduction of oil firing, in the British destroyers in 1910 and large ships in 1913 and first in the German Navy with new construction of 1926, has resulted in a great advantage. The procurement of rich oil supplies in wartime is, with many navies, an extremely serious problem, as the wartime consumption is three to four times that during peacetime. It need only be mentioned that the quality of the oil must be given considerable attention.

INDEPENDENCE FROM SHIPYARD REPAIRS.

Finally, the usefulness and the cruising range of a warship is partly determined by its dependence upon shipyards for repairs. The maximum fuel supply and the greatest calculated cruising range are of small value if the power plant does not remain free from trouble in the meantime. Warship power plants must be built so that they require but a few weeks' overhauling at the yard once a year or even once every two years. All necessary current maintenance and repair must be accomplished by means aboard ship. These means include specialized knowledge on the part of the ship's force, such as that concerning special materials and their treatment, and special tools. Maintenance facilities in a warship are very limited. These considerations demand that the navies must be able to contend with a superior enemy in a strategically unfavorable position and with no outside support. Maximum simplicity, ease of repair, and sufficient accessibility oppose the desire for increased maximum speed and highest economy. It is necessary in such a case to find the best compromise.

In this relation the large ship requires greater security than does the small, light ship. This deficiency is greater in fleets of large ships with heavy power units than with those made up mostly of small ships in greater numbers. With a torpedo boat, the exchange of engines is no longer any great difficulty. The overlying deck is opened, the engines are interchanged, and the deck welded together again. With a large ship the exchange of large engines or whole boilers requires extensive constructional work in the numerous overlying and partially armored decks. The repairs become, therefore, much more extensive and prolonged.

It is instructive in the case of German naval work to follow the extent to which the decisions concerning the conduct of naval warfare would be influenced by the repairs and their effect on ships ready for battle.

The British Lord of the Admiralty, Admiral Lord Jellicoe, mentioned, for example, the numerous condenser troubles which, during the first four months of the war of 1914 led to the long unserviceability of four of the strongest battleships and their undependable service at sea (5).

The detrimental effect of extensive maintenance and repair on active service is perhaps best shown by a study of the submarine warfare of 1914 to 1918. Vice-Admiral Michelson writes (6) that, of the total number of submarines, an average of one-third lay at the docks under repair, one-third were on the way to or from the sphere of action, and only one-third were available for action.

Such heavy dependence on the service of the yards ties up considerable labor which could be used on new construction or in fighting at the front.

PERSONNEL RELATIONS ABOARD.

The crew of a warship serves a comparatively short time and is subject to frequent change. The complexity of the technical requirements of modern propulsion units makes the highest demands on professional and technical developments and studies with regard to the mechanical equipment. But the most valuable and complete plant is of little use when the average military man cannot run it under difficult conditions. It is the human being who runs the plant and upon whom its success or failure depends. Such a situation requires considerations which must lead to simplicity of the main propulsion unit, and stability in construction so that a wise compromise can be made between often differing but equivalent possibilities.

TABLE 1. INCREASE IN MAXIMUM SPEED OF BATTLESHIPS.

Name	*Commissioned*	*Maximum Speed, Knots*	*Maximum Power, SHP*
Dreadnought (England)	1906	21.5	24,700
Nassau (Germany)	1908	20.3	28,100
Malaya (England)	1915	25.0	75,000
Baden (Germany)	1915	22.3	55,000
Colorado (United States)	1921	20.7	37,400
Nelson (England)	1925	23.5	45,000
Dunkerque (France)	1935	30.0	125,000
Littorio (Italy)	1937	30.0	150,000
Prince George V. (England)	1938	30.0	166,000
Richelieu (France)	1938	33.0	160,000

TABLE 2. WEIGHT PROPORTIONS OF THE MAIN PROPULSION UNITS ON DIFFERENT CLASSES OF SHIPS.

Class of Ship	*Percentage by Weight of the Rated Displacement*
Battleships	10% to 12%
Cruisers	21% to 25%
Submarines	30% to 35%
Destroyers	42% to 48%

TABLE 3. COMPARISON OF TWO DIFFERENT OLD GERMAN CRUISERS.

	Dresden	*Leipzig*
Construction period	1916 to 1918	1928 to 1931
Rated displacement, tons	6,300	6,740
Weight, main propulsion unit, tons	1,520	1,630
Maximum speed, V, knots	27.5	32.5
Maximum power output, SHP	49,000	72,000
Length, L, at the construction water line, feet	491	544
Beam, B, feet	46.9	53.5
Draught, feet	19.80	15.29
Length-beam ratio, L/B	10.5	10.2
Speed-length ratio, $V/\sqrt{L}$	1.24	1.37
Power-displacement ratio, SHP per ton	7.8	10.7
Weight proportion of displacement	24.2%	24.3%
Unit weight of the main propulsion unit, pounds per SHP	62	45

TABLE 4. EVOLUTION OF THE UNIT WEIGHTS OF THE MAIN PROPULSION UNITS (3).

Motive Power	*Year Built*	*Heavy Ships*	*Light Ships*	*Ratio of Heavy to Light Ships*
Reciprocating engines, wide water-tube boilers, coal fired	1908	200 pounds per HP	55 pounds per HP	3.6 to 1
Direct connected turbine drive, narrow water-tube boilers, and oil fired. Saturated steam at 265 pounds	1904 to 1914	130 pounds per SHP	40 pounds per SHP	3.3 to 1
Geared turbine drive, narrow water-tube boilers, oil fired. Superheated steam at 400 pounds and 650 degrees	1935	40 pounds per SHP	24 pounds per SHP	1.6 to 1

TABLE 5. UNIT WEIGHTS OF MODERN MAIN PROPULSION UNITS.

Class of Ship	*Unit Weight, Pounds per SHP*
Surface ships:	
Battleships with steam propulsion	35 to 44
Battleships with Diesel propulsion	46 to 53
Cruisers and Aircraft Carriers	35 to 44
Destroyers	26 to 33
Torpedo Boats	18 to 24
Speed Boats with Diesel motors	7.7 to 9
Speed Boats with Gasoline motors	4.4 to 6.6
Submarines:	
Large	62 to 77
Small	to 180

TABLE 6. COMPARISON OF ENGLISH CRUISERS WITH APPROXIMATELY THE SAME DISPLACEMENT.

Name	*Year Commissioned*	*Displacement, Tons (English)*	*Speed, V, Knots*	*Power Output*	*Armament*	*Crew*	*L, Feet*	*B, Feet*	*D, Feet*	*L/B*	$V/\sqrt{L}$
Eclipse	1894	5250 (5680)*	20	9,800 HP	11—15.0 cm. 8— 7.6 cm. 7— 4.7 cm.	437	350.0	53.5	20.4	6.55	1.07
Challenger	1902	5300 (5970)	21.1	13,000 HP	11—15.2 cm. 8— 7.6 cm.	460	356.0	56.2	20.7	6.33	1.36
Weymouth	1910	4800 (5300)	25.6	26,000 SHP	8—15.2 cm. 4— 4.7 cm.	380	430.0	48.7	15.4	8.85	1.24
Despatch	1919	4850	29	40,000 SHP	6—15.2 cm. 3—10.2 cm. 4— 4.7 cm. 2— 4.0 cm.	462	473.0	48.7	16.4	9.73	1.33
Arethusa	1934	5200	32.2	64,000 SHP	6—15.2 cm. 4—10.2 cm. 4— 4.7 cm. 2— 4.0 cm.	450	500.0	51.3	13.8	9.77	1.43

* The numbers in parentheses show the construction displacement.

TABLE 7. SPEED-LENGTH RATIO.

Class of Ship	$V/\sqrt{L}$
Battleships, V less than 23 knots	0.83 to 0.94
Battleships, V = 25 to 33 knots	1.05 to 1.16
Aircraft Carriers	1.05 to 1.27
Cruisers	1.21 to 1.43
Destroyers	1.65 to 2.20
Speed Boats, with regular ship form	3.58 to 4.95
Speed Boats, flat bottom	4.95 to 6.63

TABLE 8. FUEL CONSUMPTION OF THE PORTUGESE DESTROYERS *Vouga* AND *Lima* AT MAXIMUM CONTINUOUS TRAVEL AND CRUISING.

Commissioned	1933	
Rated displacement, tons	1,383	
Maximum displacement, tons	1,620	
Maximum power output, SHP	33,000	
Maximum speed, V, knots	38.5	
Length, L, feet	307	
Speed-length ratio, $V/\sqrt{L}$	2.19	
	Maximum Continuous Travel	*Cruising*
Speed, knots	36.65	15.01
Power at this rate, SHP	31,280	1.770
Proportion of maximum power, per cent	94.7	5.4
Fuel consumption for all purposes, pounds per SHP	0.747	1.028

TABLE 9. FUEL CONSUMPTION FOR ENGLISH WARSHIPS.

Class	*Name*	*Commissioned*	*Power, SHP*	*Speed, Knots*	$\frac{V}{\sqrt{L}}$	*Steam Pressure, Pounds*	*Steam Temperature, Degrees F.*	*Unit Weight, Pounds per SHP*	*Floor Space, 1000 SHP per Square Foot*	*Fuel Consumption, Pounds per SHP*
Battleship	*Malaya*	1915	75,000	25	1.02	245	Sat.	106	.....	1.237
	Nelson	1925	45,000	23	0.89	260	550	102	.....	0.789
Battle Cruiser	*Repulse*	1916	112,000	31.5	1.17	245	Sat.	111	1.42	1.260
	Hood	1918	144,000	31	1.09	245	Sat.	83	1.16	1.242
Cruiser	*Cleopatra*	1915	40,000	29	1.41	245	Sat.	48	1.02	1.309
	Enterprise	1919	80,000	33	1.39	260	Sat.	43	0.92	1.150
	Berwick	1926	80,000	31.5	1.30	260	550	45	1.00	0.878
	Sussex	1928	80,000	32.25	1.33	260	550	45	1.01	0.859
	Leander	1931	72,000	32.5	1.41	310	600	44	0.93	0.811

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MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

INFLAMMABILITY OF GASES.—Reprinted from Refrigerating Engineering, September, 1939, published by the American Society of Refrigerating Engineers, New York, N. Y.

A thorough study of the literature regarding the limits of inflammability of gases and vapors has been made by H. F. Coward and G. W. Jones of the Bureau of Mines, publishing their findings as Bulletin 279, 1939. This is a complete critical review, a revision of a first edition which came out in 1928; the present bulletin is carefully indexed, and sells for 20 cents at the Government Printing Office.

The dilution limit of inflammability, or simply the limit of inflammability, is the border-line composition; a slight change in one direction produces an inflammable mixture, in the other a non-inflammable mixture. There are two limits, upper and a lower, for each pair of combustible gases and supporters of combustion. Experimental determination is difficult, accounting for contradictory results cited. The opinion of the authors favors the values shown in their table, reproduced herewith.

DIESEL ENGINE PRINCIPLE.—Army and Navy Register, Washington, D. C., August 12, 1939.

The principle of high-compression ignition, fundamental in the Diesel engine, was discovered originally by the primitive people of the Malay Peninsula and the East Indies long before their first contact with white men and was rediscovered centuries later by German engineers.

Summarized Data on Limits of Inflammability of Gases and Vapors[1]

Gas or vapor	Limits in air, per cent				Limits in oxygen, per cent				Oxygen percentage below which no mixture is inflammable	
	Lower		Higher		Lower		Higher		Nitrogen as diluent of air	Carbon dioxide as diluent of air
Hydrogen	4.1	4.0	74	...	...	4.0	94	...	5.0	5.9
Ammonia	...	16	...	27	...	15	...	79	...	...
Hydrogen sulfide	...	4.3	...	45.5	...	...	...	...	...	...
Carbon sulfide	1.25	...	44	50	...	...	...	...	...	...
Carbon monoxide	12.5	...	74	...	...	...	...	...	5.6	5.9
Methane	5.3	(5.0)	14	15	...	5.4	...	59	12.1	14.6
Ethane	3.2	...	12.5	...	...	4.1	...	50	11.0	13.4
Propane	2.4	...	9.5	...	...	...	...	...	11.4	14.3
Butane	1.85	...	8.4	...	...	...	...	...	12.1	14.5
Isobutane	1.8	...	8.4	...	...	...	...	...	...	...
Pentane	1.4	...	7.8	...	...	...	...	...	12.1	14.4
Isopentane	...	1.3	...	...	...	...	...	...	...	...
Hexane	1.2	...	6.9	...	...	...	...	...	11.9	14.5
Heptane	...	1.0	...	6.0	...	...	...	...	...	...
Octane	.95	...	...	...	...	...	...	...	...	...
Nonane	...	.8	...	...	...	...	...	...	...	...
Decane	...	.7	...	...	...	...	...	...	...	...
Ethylene	3.0	2.75	29	...	3.1	2.9	80	...	10.0	11.7
Propylene	...	2.0	...	11.1	2.1	...	53	...	11.5	14.1
Butylene	...	1.7	...	9.0	...	...	...	...	...	...
Amylene	...	1.6	...	...	...	...	...	...	...	...
Acetylene	2.5	(2.3)	...	80	...	...	...	...	...	...
Benzene	1.4	...	6.7	...	...	...	...	...	...	...
Toluene	1.4	1.3	...	6.7	...	...	...	...	...	...
o-Xylene	...	1.0	...	6.0	...	...	...	...	...	...
Cyclopropane	...	2.4	...	10.4	...	2.45	...	63	...	...
Cyclohexane	1.3	1.2	8.3	...	...	...	...	...	...	...
Methyl cyclohexane	1.2	...	...	...	...	...	...	...	...	...
Methyl alcohol	7.3	6.7	...	[2]36	...	...	...	...	10.3	13.5
Ethyl alcohol	4.3	3.3	...	[2]19	...	...	...	...	...	...
Propyl alcohol	...	2.5	...	...	...	...	...	...	...	...
Iso-Propyl alcohol	...	2.6	...	...	...	...	...	...	...	...
Butyl alcohol	...	1.7	...	...	...	...	...	...	...	...
Iso-Butyl alcohol	...	1.8	...	...	...	...	...	...	...	...

Methyl alcohol	7.3	6.7	...	36	...	...	...	...	13.5	13.5
Ethyl alcohol	4.3	3.3	...	[3] 19	...	...	...	...	...	...
Propyl alcohol	...	2.5	...	...	...	...	...	...	...	...
Iso-Propyl alcohol	...	2.0	...	...	...	...	...	...	...	...
Butyl alcohol	...	1.7	...	...	...	...	...	...	...	...
Iso-Butyl alcohol	...	1.8	...	...	...	...	...	...	...	...
Amyl alcohol	...	1.2	...	...	...	...	...	...	...	...
Iso-Amyl alcohol	...	1.2	...	...	...	...	...	...	...	...
Allyl alcohol	...	2.4	...	...	...	...	...	...	...	...
Methyl ethyl ether	...	2.0	...	10.1	...	...	...	...	...	...
Ethyl ether	1.9	1.85	48	...	...	2.1	...	82	...	...
Vinyl ether	...	1.7	...	27	...	1.8	...	85	...	...
Ethylene oxide	3.0	...	80	...	...	...	...	...	...	...
Propylene oxide	2.1	...	21.5	...	...	...	...	...	...	...
Dioxan	...	2.0	...	[3] 22	...	...	...	...	...	...
Diethyl peroxide	...	2.35	...	...	...	...	...	...	...	...
Acetaldehyde	...	4.0	...	57	...	...	...	...	...	...
Croton aldehyde	...	2.1	...	[3] 15.5	...	...	...	...	...	...
Furfural	[4] 2.1	...	...	...	...	...	...	...	...	...
Paraldehyde	...	1.3	...	...	...	...	...	...	...	...
Hydrocyanic acid	...	5.6	...	40	...	...	...	...	...	...
Acetone	3.0	2.55	11	13	...	...	...	...	13.5	15.6
Methyl ethyl ketone	...	1.8	...	10	...	...	...	...	...	...
Methyl propyl ketone	...	1.5	...	[3] 8.5	...	...	...	...	...	...
Methyl butyl ketone	...	1.2	...	[3] 8	...	...	...	...	...	...
Methyl formate	5.9	5.0	20	[3] 23	...	...	...	...	...	...
Ethyl formate	2.7	2.7	13.5	[3] 16.5	...	...	...	...	...	...
Methyl acetate	...	3.1	...	[3] 15.5	...	...	...	...	...	...
Ethyl acetate	2.0	2.2	8.5	[3] 11.5	...	...	...	...	...	...
Propyl acetate	2.0	1.8	...	[3] 8.0	...	...	...	...	...	...
Iso-Propyl acetate	...	1.8	...	[3] 7.8	...	...	...	...	...	...
Butyl acetate	[3] 1.7	...	...	...	...	...	...	...	...	...
Ethyl nitrite	...	3.0	...	...	...	...	...	...	...	...
Methyl chloride	10.7	8.0	17.4	19	...	8.0	...	66.0	...	...
Methyl bromide	...	13.5	...	14.5	...	...	...	...	...	...
Ethyl chloride	4.2	4.0	14.3	14.3	...	...	...	...	...	...
Ethyl bromide	...	6.7	...	11.2	...	...	...	...	...	...
Ethylene dichloride	6.2	...	[3] 15.9	...	...	...	...	...	...	...
Dichloroethylene	9.7	...	12.8	...	...	...	...	...	...	...
Propylene dichloride	...	3.4	...	[3] 14.5	...	...	...	...	...	...
Amyl chloride	...	1.4	...	...	...	...	...	...	...	...
Vinyl chloride	4.0	...	22.0	...	...	...	...	...	...	...
Diethyl selenide	...	2.5	...	...	...	...	...	...	...	...
Tin tetramethyl	...	1.9	...	...	...	...	...	...	...	...
Lead tetramethyl	...	1.2	...	...	...	...	...	...	...	...
Pyridine	...	1.8	...	12.4	...	...	...	...	...	...

[1] Values in italics were obtained in closed apparatus. Values in parentheses are for turbulent mixtures. [2] At 60° C. [3] At 100° C. [4] At 125° C. [5] At 20° C.

One of the fire-lighting gadgets of the Malays, the fire piston, described by some ethnologists as the most remarkable of primitive inventions, is now in the collections of the Smithsonian Institution. It consists of a tightly wrapped plunger which is forced into a wooden cylinder at the bottom of which is placed a bit of tinder. The plunger, hit by the hand, compresses the air beneath it and generates sufficient heat to light the tinder. The Malays then take out this tinder, fan it into a flame, and use it to start a fire.

In the Diesel engine the same principle is used for the ignition of oil, making possible an engine without any special ignition system. This invention of some unknown Malay—or more probably development over several generations—spread throughout the Malaysian area and was at least a thousand years in advance of the German engineers. It is probably the most efficient of primitive fire-making methods, which included rubbing sticks together by means of the fire saw or the fire plow, getting sparks from flint when struck against iron pyrites, and the use of the fire drill consisting of two sticks set in motion with a bow or strap or operated as a pump drill.

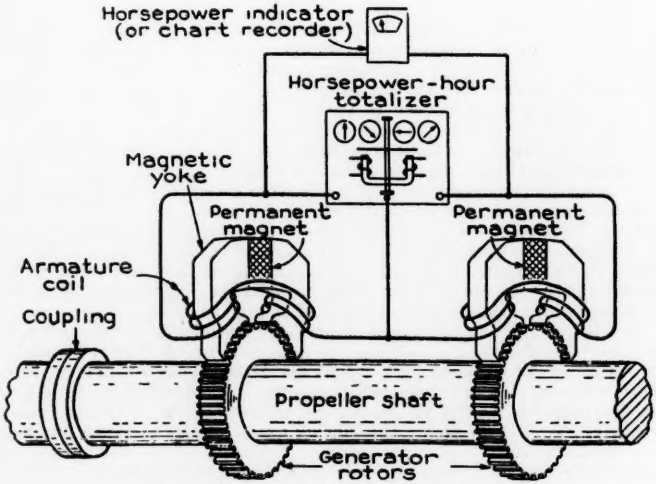
This is by no means an isolated instance of "inventions" of primitive peoples preceding some of the most brilliant ideas of twentieth century inventors, says Herbert W. Krieger, U. S. National Museum curator of ethnology. There was a striking case a few years ago when it was found that Fiji Islanders long ago had solved an outstanding problem of the American textile industry. This was the problem of winding a spool of cord in such a way that it could be unwound with even tension. Engineers and inventors worried over it for years, and when a successful device was finally hit upon, essentially the same principle was found in the Fiji twine ball in the National Museum collections. This prevented patenting the device and resulted in a saving of millions to the textile industry as a whole.

NEW METER FOR MEASURING SHAFT HORSEPOWER.—The Marine Engineer, London, England, July, 1939. The type of horsepower meter described in this article was used in the acceptance trials of the U. S. S. *Cimarron* above noted.

Of interest to marine engineers, whether they be on passenger liners, cargo vessels, tankers, or tugs, is the announcement of a new electric meter developed by the engineers of the General Electric Company of America for giving accurate and instantaneous measurements of shaft horsepower and horsepower-hours. With the new device, the engineer can check the performance of his propulsion equipment over a wide range of speeds, can compare the rate of fuel consumption with power output under varying conditions, and, in general, can check the efficiencies of boilers and other equipment. Readings can be taken directly from the scale on the dial of the meter, thus eliminating the need for conversion formulas and tables.

Up to the present, this equipment has been used by the Sun Shipbuilding & Dry Dock Company for checking the performance of the power plants on its new ships. Other service at sea demonstrates that it will operate successfully under severe conditions and still maintain its accuracy.

The new meter consists essentially of two electric generators, mounted on the propeller shaft and connected to indicating devices which can be located any distance away. The generator rotors are built in halves which are assembled on the shaft after the latter has been installed in the ship. The stator bearings are also made in halves, so that the stator structure is assembled on the rotors after they are in place. The stator is restrained from rotat-



Layout of the new meter, which is of American origin

ing by a bar which is pinned to one side at one end of it and, at the other end, to a bracket on the ship's structure. This arrangement allows sufficient flexibility to provide for lateral or vertical motion of the shaft without disturbing the relative position of the rotors and stators.

The stators of each generator are initially adjusted so that, when no torque is being transmitted by the revolving shaft, the voltages generated by the two generators are exactly 180 degrees apart in phase. Thus, these voltages balance each other so that the resultant voltage is zero and the indicator hands stand at 0 on the dial. When a load is placed on the revolving shaft, the torque will cause a small amount of twist in the shaft, and the two voltages will therefore no longer be 180 degrees out of phase and the resultant voltage, being proportional both to the shaft twist and to the propeller speed, will register on the indicator as horsepower.

The indicating portion of the instrument can be either or both a continuous indicator showing instantaneous horsepower or a meter showing totalized horsepower-hours. A further refinement can be the fitting of an automatic log record in which the instantaneous power is recorded on a moving roll of paper throughout the voyage.

The entire unit is completely self-contained and no external source of power is needed. It can be easily installed, since it requires no more than at most 4 feet of shaft, requires little attention, and its calibration can be easily checked at any time.

This new instrument is being handled in Great Britain by the British Thomson Houston Co., Ltd., Rugby.

RELATIVE COST OF MOTORSHIPS AND STEAMSHIPS.—The Log of August, 1939, published by The Log Publications, Inc., San Francisco, Calif.

The figures given below, extracted from bids submitted to the U. S. Maritime Commission for Design C-1 cargo vessels, are given to show the relative first cost of steam and motorships. Note that, in most cases, the differential in first cost of Diesel over steam is less than that prevailing in Europe, where the motorship predominates:

Bidder	*No. Ships*	*Price per Ship*		*Difference*	
		Steam	*Diesel*	*Dollars*	*Per Cent*
Consolidated Steel Corporation..	4	1,869,000	1,948,000	79,000	4.24
Tampa Shipbuilding & Engineering Co.	5	1,784,670	1,821,870	37,200	2.085
Ingalls Shipbuilding Corporation	5	1,975,234	2,015,000	39,766	2.02
Federal Shipbuilding & Dry Dock	5	1,879,000	2,042,000	163,000	8.64
Sun Shipbuilding & Dry Dock....	5	1,980,000	1,980,000	.....	.....
Pusey & Jones	2	2,220,197	2,350,310	130,113	5.86
Seattle Tacoma Ship Building Co.	5	2,201,300	2,229,300	28,000	1.27
Los Angeles Shipbuilding & Dry Dock	4	2,310,000	2,389,000	79,000	3.42
Bethlehem Steel Corporation—					
Sparrows Point, Md.	5	2,272,300	2,290,100	17,800	.782
Union Plant, Calif.	5	2,409,000	2,426,000	17,000	.704
Staten Island	2	2,630,000	2,659,000	29,000	1.102
*General Engineering & Dry Dock	5	2,181,000	2,188,000	7,000	.32
*Newburgh Shipbuilding Corporation	5	1,512,000	1,612,000	100,000	6.61
*Cramp Shipbuilding & Dry Dock Co.	5	2,125,000	2,117,000	—8,000	—.378

* (No bid bond or check submitted.)

Note: Bids based on shelter deck design. Adjusted prices except in case of Tampa, Pusey & Jones, and Sun, which are based on fixed prices. Prices based on the maximum number of ships for which each yard bid. Prices shown are for geared Diesel drive except Sun Shipbuilding bid on engines of their own manufacture, direct drive and an addition for geared drive.

ASSOCIATION NOTES.

ANNUAL MEETING.

The Annual Meeting of the Society was held in the Navy Department at Washington, D. C., on Tuesday, October 3, 1939.

Nominations for officers of the Society for the calendar year 1940 were made as follows:

For President:

Captain Henry Williams (CC), U. S. N.

For Secretary-Treasurer:

Lieut. Commander Guy Chadwick, U. S. N.
Lieut. Commander James E. Hamilton, U. S. N.

For Member of Council:

Commander F. W. Pennoyer, Jr., U. S. N.
Captain Lybrand P. Smith, U. S. N.
Captain H. Gordon Donald, U. S. N.
Captain H. M. Cooley, U. S. N.
Captain E. D. Almy, U. S. N.
Lieut. Commander J. B. Dow, U. S. N.
Captain J. A. Furer (CC), U. S. N.
Commander E. E. Brady (CC), U. S. N.
Commander John N. Heiner, U. S. C. G.
Commander Charles J. Odend'hal, U. S. C. G.
Mr. George B. Ferrier.
Mr. Harold K. Beck.
Mr. W. B. Armstrong.
Mr. Charles G. Cooper.
Mr. Jesse B. Lunsford.
Mr. Howard J. Ball.

Polls close at 4:15 on 26 December, 1939.

It was voted to hold the Annual Banquet in the year 1940. Announcement of the date and other details will be made in the near future.

MEMBERSHIP.

The following have joined the Society since the publication of the August, 1939, JOURNAL:

NAVAL.

Eastman, F. G., Lieutenant, U. S. C. G.

Forsyth, Edward C., Lieut. Commander, U. S. N.

Hirschberger, Carl R., Ensign, U. S. N.

How, Harland, 270 West Elm St., Titusville, Pa.

Kuhn, Cyril D., Lieut., U. S. N. R., 7040 Olcott Avenue, Hammond, Ind.

Peterson, C. W., Ensign, U. S. C. G.

Powell, Edgar S., Lieutenant, U. S. N.

Proctor, William E., Lieutenant, U. S. N. R., care Proctor Engineering Co., 102-106 Key Highway, Baltimore, Md.

Reich, Eli T., Lieutenant, U. S. N.

Templeton, Thomas H., Lieut. Commander, U. S. N.

Will, John M., Lieut. Commander, U. S. N.

CIVIL.

Campbell, Perry B., in charge of Naval Work, Buffalo Forge Co., 490 Broadway, Buffalo, N. Y.

Clarke, Charles M., 90 New York Ave., Baldwin, N. Y.

Frear, Clyde L., 4203 4th St., North, Arlington, Va.

Keenan, Walter F., Vice President, Foster Wheeler Corporation, 165 Broadway, New York, N. Y.

Klingensmith, J. A., 3001 Porter St., N. W., Washington, D. C.

Klosson, Michael M., Chief Engineer, Buffalo Pumps, Inc., Buffalo, N. Y. Residence, 1066 Colvin Boulevard, Kenmore, N. Y.

Peterson, A. G., Vice President, Buffalo Pumps, Inc., Buffalo, N. Y. Residence, 149 Admiral Road, Buffalo, N. Y.

Post, Robert E., Washington Manager, Fairbanks, Morse & Co., 1427 Eye St., N. W., Washington, D. C.

Reagle, Charles M., Vice President, Cooper-Bessemer Corporation, 25 W. 43d St., New York, N. Y.

Toner, Harold J., 8508 Cedar St., Silver Spring, Md.

ASSOCIATE.

Clark, Thomas, Jr., 47 Elm St., Elizabeth, N. J.

Nicholson, Robert, 2312 Mountain St., Philadelphia, Pa.

Potter, James H., 509 West 110th St., New York, N. Y.

EUROPEAN JOURNALS AND THE WAR.

The non-receipt by a subscriber of any European chemical or other scientific journal seriously needed as research material should be promptly reported to the American Documentation Institute.

The Cultural Relations Committee of ADI, which cooperates closely with the Cultural Relations Division of the Department of State, is working on this problem, and hopes to be able to surmount such war obstacles as interrupted transportation, embargoes and censorship, which so grievously affected the progress of research during the last war.

The principle should be established, if possible, that the materials of research having no relation to war shall continue to pass freely, regardless of the countries of origin or destination.

Reports, with full details of where subscription was placed and name and address of subscriber, volume, date and number of last issue received, should be addressed to: American Documentation Institute, Bibliofilm Service, care of U. S. Department of Agriculture Library, Washington, D. C.

EUROPEAN JOURNALS AND THE WAR

The non-receipt by a subscriber of any European chemical or other scientific journal seriously needed as research material should be promptly reported to the American Documentation Institute.

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